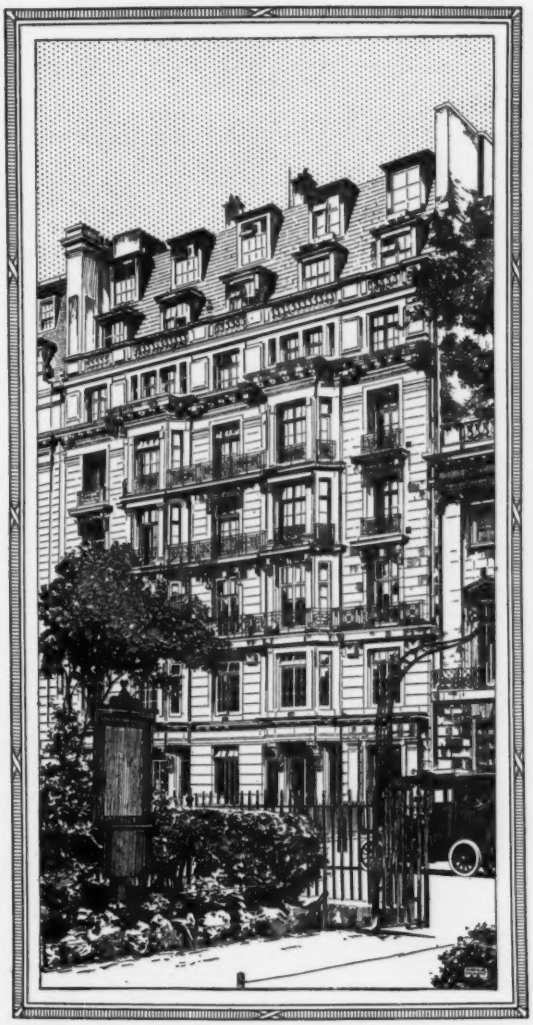
The ENGLISH ELECTRIC JOURNAL



Queen's House from Lincoln's Inn Fields.

All rights of republication, including translation of articles, are reserved.

ONE OF THE WATER-TURBINE RUNNERS FOR THE LINTON LOCK HYDRO-ELECTRIC STATION OF THE CITY OF YORK.
The largest Runner of its kind installed in this country. It has an exit diameter of 10 feet and weighs 5½ tons.

The English Electric Journal

Vol. II. No. 5. JULY, 1923 One Shilling

CONTENTS.

	PAGE
Two Important Contracts	215
Linton Lock Hydro-Electric Station of the City of York	217
Regeneration Tests on Locomotives	226
Progress Notes on "English Electric" Steam Turbine Plant	229
Electricity in the Portland Cement Industry	233
Electric Propulsion of Ships	245
Reversing Mill Drive at Messrs. Cammell Laird's Penistone Works	256

EDITORIAL.

All Communications respecting Editorial Contents should be addressed to The Editor, The English Electric Journal, Queen's House, Kingsway, London, W.C.2.

TWO IMPORTANT CONTRACTS.

The urgent necessity for the placing of every possible order by those who are in a position to do so, with a view to alleviating the menace of unemployment during the coming winter, was recently emphasized by the Prime Minister. It is, therefore, with the greatest satisfaction that we refer to two contracts of some magnitude which have been awarded to the Company during the present month.

While uncertainty as to the issue of Continental affairs intensifies, day by day, the stagnation of our export trade, it is of the first importance that reconstruction and development schemes should be pushed ahead, so that the national efficiency and manufacturing capacity are conserved in readiness for the eventual recuperation of our foreign customers.

The orders placed by the Southern Railway for electrical train equipments for the South-Eastern Suburban lines are a reminder of the progress which is being made with the first electrification scheme to be undertaken since the war by a British main line railway, and are

Tech
Pub.

probably the largest contracts of their kind ever placed. The completion of this and other similar schemes throughout the country will do much to add to the efficiency and comfort of travel in the more densely populated areas; but the point of greatest importance at the moment is that in their execution a large amount of employment will be afforded for some time to come.

To this Company has been entrusted the manufacture of 508 railway motors, each of 300 H.P., which will be fitted to motor-coach trains for working the first section of the lines to be electrified, embracing a radius of about fifteen miles from the London termini. These machines will be manufactured at the Dick, Kerr Works, Preston, and will be of the D.K. 77 self-ventilating type, designed for working on a 600-volt, direct-current, conductor rail system, and for a gear ratio of 2·81.

The complete scheme for this electrification provides for the conversion to electrical working of all the lines within about thirty miles of the Metropolis, and it is interesting to note that after an exhaustive enquiry it has been decided that a separate power station will not be erected, but the necessary supply will be taken from the London Electric Supply Corporation's Deptford Power Station.

Another important order is for plant aggregating some 54,000 H.P. for the complete electrical equipment of the new Steel Works and Plate Mills of the Consett Iron Company, in connection with the most important steel works reconstruction carried out in this country for a considerable time. The addition of this mill to the list of those electrically equipped by the English Electric Company will still further strengthen the unique position which this company occupies in the field of rolling mill equipment.

The Consett Company have been well-known manufacturers of steel plates for many years and the completion of the new mills will, it is anticipated, put them in an exceptionally good position to meet modern conditions.

Four entirely new mills are being put down—a 40-in. Slabbing Mill, a 42-in. Plate Mill, a 32-in. Light Plate Mill and a Chequer Plate Mill.

The first two will be of the two-high reversing type and the drives will, therefore, be on the Ilgner system, the main reversing motors being precisely similar for the two mills; each will consist of a double-armature direct-current motor of 14,000 H.P. The two Ilgner sets, also duplicates, will be driven by 2,500 H.P. three-phase motors running at 600 R.P.M. and will have 48-ton flywheels. The Light Plate Mill and the Chequer Plate Mill will be driven by induction motors of 2,500 H.P. and 750 H.P. respectively. The rolling mills will be supplied by Messrs. Davy Brothers.

The lay-out and electrical equipment of the mills will embody some novel features, to which we hope to make detailed reference at a later date.

The Linton Lock Hydro-Electric Station of the City of York.

Owing to the high price of coal at the end of the War and in the following years, the York Corporation made a thorough study of the advisability of erecting a hydro-electric power station in the neighbourhood of the city as the best means of meeting the increasing demand for electricity. It was found that one of the most favourable sites was on the River Ouse at the Linton Lock, about 11½ miles from York. As will be seen from the site plan shown in Fig. 2 there is a bend in the river at this point, which facilitates the arrangement of the weir and of the power station building. The difference in water levels varies from 1 ft. 4 in. to 11 ft. 4 in., giving an average fall during the year of 8·83 feet.

The River Ouse, like most rivers without natural compensation, has a very variable discharge. Roughly speaking, the discharge varies from 50,000 cubic feet per minute in the dry periods to 200,000 cubic feet per minute in the wet months. Taking 100,000 cubic feet per minute as an average with 8·83 feet head, 1,200 H.P. could be expected

FIG. 1. THE POWER HOUSE AND FOREBAY.

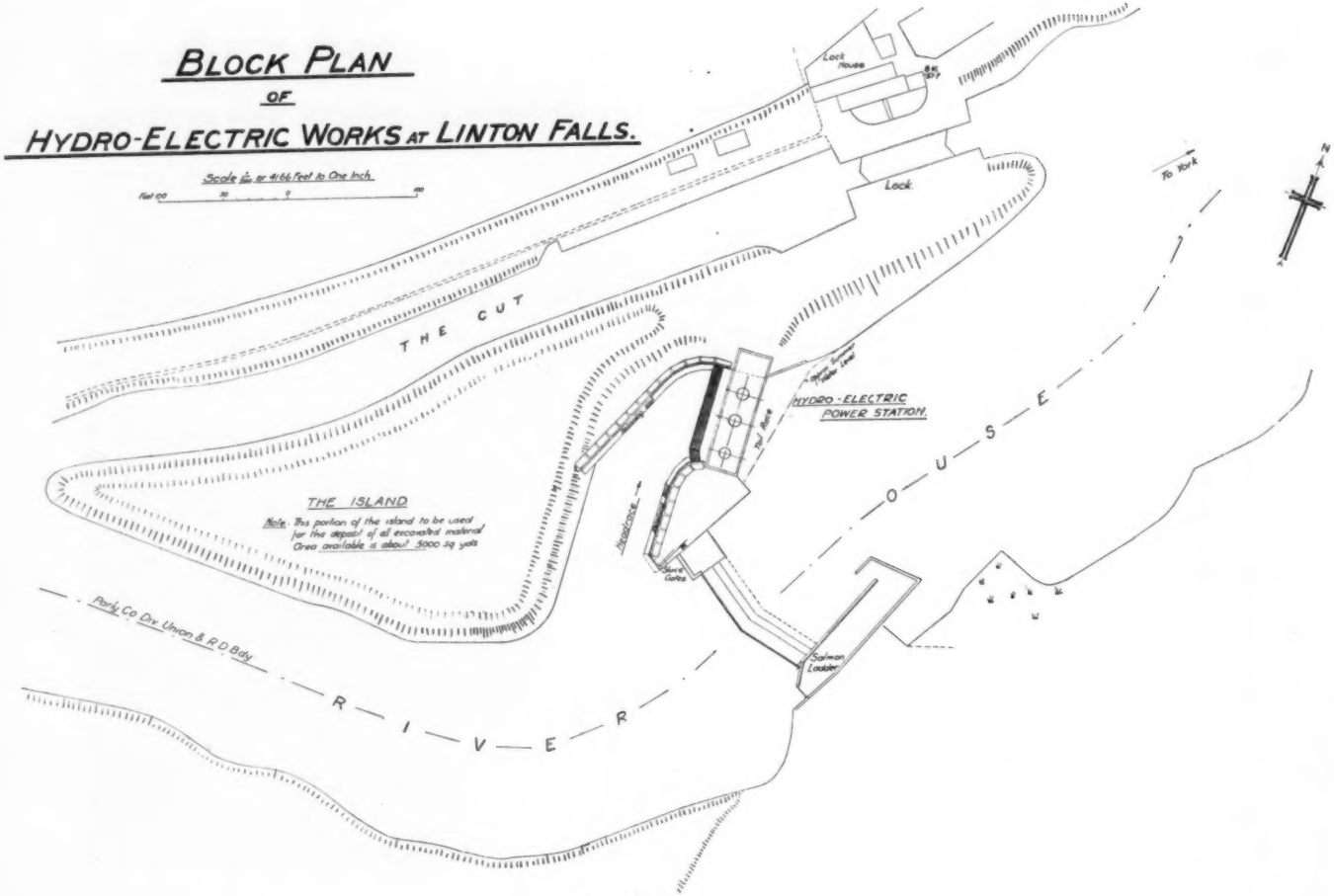

BLOCK PLAN
OF
HYDRO-ELECTRIC WORKS AT LINTON FALLS.
Scale 1/500 or 4.166 Feet to One Inch.
Feet 00 10 0 20
Lock House
Lock
THE CUT
To York
N
HYDRO-ELECTRIC POWER STATION
THE ISLAND
Note. This portion of the island to be used for the deposit of all excavated material Area available is about 5000 sq yds
Intake
Sluice Gates
Tail Race
Salmon Ladder
Party Co Drv Union & R O Bdy
R I V E R
O U S E

FIG 2. PLAN OF SITE.

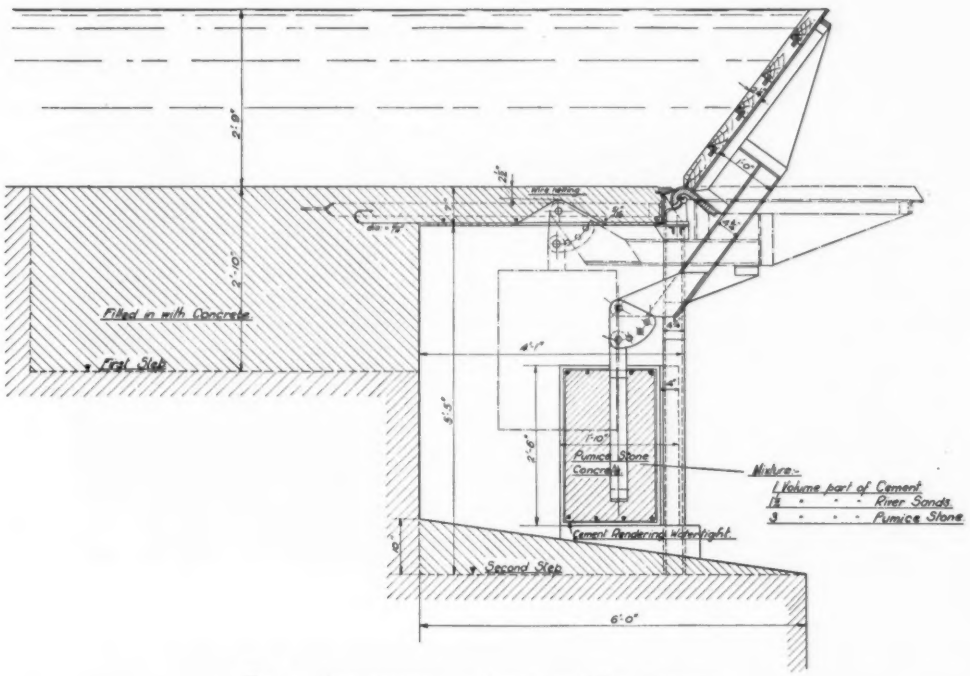


FIG. 3. ARRANGEMENT OF AUTOMATIC WEIR SHUTTER.

from the proposed Power Station at Linton Lock. A close calculation showed that the available energy, in normal years, would exceed 2,750,000 KW.-hours per annum.

In these circumstances the scheme was considered a sound one, and it was decided to go ahead with it. In order to concentrate supervision and responsibility and to make the co-ordination of work easier, the York Corporation, in issuing their specifications, decided to include the civil works, the buildings, and the supply of plant in one comprehensive contract. This was eventually awarded to the English Electric Company, who designed and erected the complete power station which will now be described.

It can be seen from Fig. 2 that the water is led to the forebay by means of a weir put across the river. It had been agreed with the riverside owners that the water level due to this weir was not to exceed 2 ft. 9 in. above the existing sill; on the other hand, the York Corporation wanted to use as much as possible of the available waterfall. To satisfy these two requirements the contractors suggested, and it was agreed, that two automatic weir shutters should be supplied. As will be seen from Fig. 3, the automatic operation of this apparatus is brought about by the variable moment of a counterweight balancing the weight of the water acting on the shutter. Owing to the very small difference in levels which can occur during times of flood (1 ft. 4 in.) special arrangements had to be made in order to prevent the weir shutters rising under the heavier action of the counterweight when the shutter is immersed. This danger was removed by making the counterweight of pumice-stone concrete of 1·5 specific gravity; thus in the case of high water levels in the tail race, its weight is considerably reduced and the shutter cannot

FIG. 4. VIEW UPSTREAM DURING PROGRESS OF WORK.

rise inopportunely. The Automatic Weir Shutters were supplied by the Société des Barrages Automatiques, of Zurich, Switzerland.

Fig. 4 is a view upstream during the progress of the work and shows the cofferdam round the tail-race works, the weir and, near the right bank, the salmon ladder. The latter was required by the Ministry of Fisheries, and is a usual accessory of hydro-electric power stations.

On the left of the weir the water goes into the forebay, passes a strainer rack made of 3 in. by $\frac{3}{8}$ in. wrought-iron bars spaced 2 in. apart, flows under the sluice gates and enters the Power Station. The latter, which is shown in Fig. 1, is built on very friable soil of a silty nature, some 70 feet deep. Special piling work was necessary in order to ensure safe foundations, and no fewer than 110 piles had to be driven. Special precautions in the shape of retaining walls, stone paving, etc., had also to be taken to protect the river banks against floods.

Architecturally the building is very simple, the primary feature of its design being suitability for its purpose. The lighting is from the roof as the walls had to be watertight to a fair height owing to the high flood levels in the head race, and the crane runway prevents free windows higher up. The Plate facing page 224 shows the general arrangement of the building and plant.

There are three turbines, two large ones of 430 H.P. each, running at 60 R.P.M. and driving a 540 KW. generator, and one small one, of 330 H.P., running at 75 R.P.M., and driving a 210 KW. generator.

The choice of the number and of the size of these turbines was the result of a thorough study of the conditions. The efficiency of water turbines under low heads drops rapidly when they are used below 50 per cent. of their rated output, so that in order to obtain the best efficiency it is necessary to run them, as far as possible, between half and full load. Consequently, when only small quantities of water are available it is most economical to use turbines of correspondingly small full load output. On the other hand, the larger a turbine the better is its efficiency and, moreover, from

the economical point of view, the larger the sets the cheaper is the power station layout.

In the case of Linton Lock it was found that the most economical arrangement was to install the turbines described above. By using the three turbines in accordance with the following working table it is possible to have the running

No.	Plant running.	Available output.	Per cent. of full load on turbines.
1	Small turbine ...	0— 330 H.P.	0—100
2	One large turbine	330— 430 H.P.	77—100
3	Small and one large turbine ...	430— 760 H.P.	57—100
4	Two large Turbines	760— 860 H.P.	88—100
5	Three turbines ...	860—1190 H.P.	72—100

plant always loaded up to more than 72 per cent. of its rated full load, apart from the lower limit in No. 3 or during a few exceptionally dry periods.

This means that the Power Station, on the average, works with an hydraulic efficiency of 75 to 83 per cent. according to the available heads, and will generate in normal years 2,780,000 KW.-hours per annum.

The turbines have been designed to work economically, not only at full load, but also at partial loads. Their specific speeds have been so chosen as to give a high efficiency over a long range of varying loads and heads. Under a normal head of 8·83 ft. the specific speed of the large turbine is 82 and of the small turbine 89·5.

In order to improve the efficiency of the plant and at the same time to reduce the size of the building, the turbines are fed through concrete spirals. These lead the water to the gate apparatus in a better way than ordinary pits, and by allowing a higher water velocity show a gain in space. Moreover, as the turbines are in closed chambers they could be designed with the whole of their governing gear out of the water and easily accessible.

This arrangement also allows the turbines to be situated higher, thus securing a good exit for the draught tube without undue excavation,

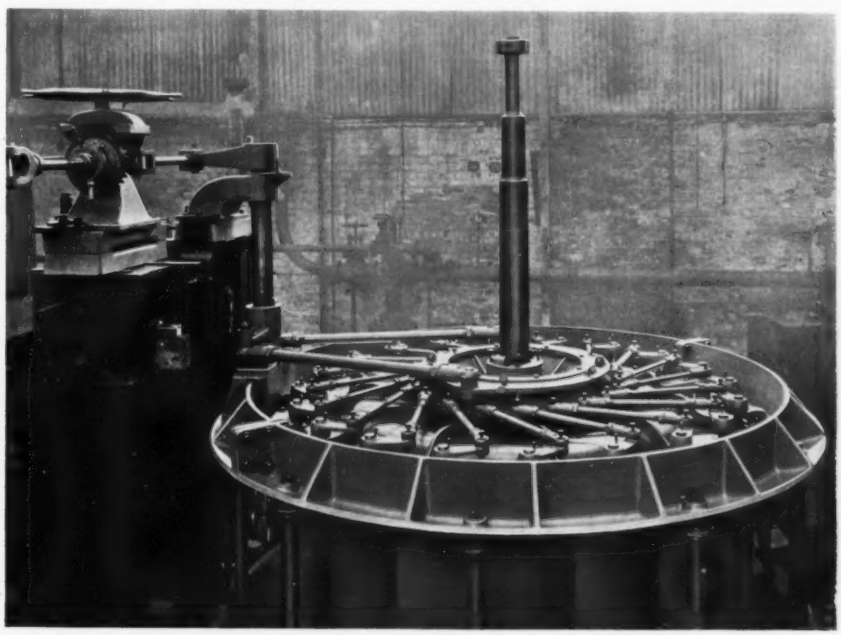


FIG. 5. GATE APPARATUS ERECTED AT THE WILLANS WORKS, RUGBY.

even in cases where the fall is small, as in the case of Linton Lock. At the same time the floor level can be put at any convenient height ; in this case, with a view to reducing the necessary volume of concrete and the length of the turbine shafts, it has been chosen level with the average water level in the forebay, and will be below the forebay level in time of floods.

From the spiral chamber the water comes into the gate apparatus, which consists of twenty guide vanes 43·3 in. high for the large turbines, and 35·5 in. high for the small one. These guide vanes are of cast iron, and are pivoted in bronze bushes carried by the foundation rings ; they are operated from above by a system of levers and linkwork. The massive foundation rings of cast iron are connected by steel pillars and built into the concrete, thus forming a good and rigid assembly. Fig. 5 shows the gate apparatus for one of the turbines in course of erection at the Willans Works, Rugby, of the English Electric Company.

The runners were very carefully designed in order to reduce the vertical axial thrust, and have balancing holes and extended cover (see Frontispiece and Plate). Owing to these balancing holes, the space between the runner and the cover is under suction, and the extended cover balances the pressure which the water exerts at entrance on the vanes. The weight of the runners is considerable owing to their dimensions ; for the large turbine, which has an exit diameter of 10 feet, it amounts to over 5½ tons.

Owing to the low fall the turbines are of the vertical shaft type. From the vertical shafts the drive is transmitted to the generator by means of bevel gears, strongly supported by cast-iron beams, which also bear the step bearing of the turbine shaft. The bevel gears are of the machine-cut, double-helical type, manufactured by the Citroen Gear Company, Limited. It is obvious that for such outputs machine-cut gears are the only suitable ones ; these gears, moreover, meshing in a gradual and smooth way run with very high efficiency and without any noise. From the gears the power is transmitted to the generators by means of flexible couplings, which in the case of the large turbines are so designed as to allow for easy connection and disconnection.

The speed of the sets is controlled by two automatic oil-pressure governors. By a very simple arrangement the servo-motor of the main set can control the gate apparatus of the two large turbines or if one of them is not running its gate apparatus can be disconnected from the servo-motor ; under the last-named conditions the horizontal shaft of the idle turbine is disconnected from the generator, and the set runs with one turbine only in exactly the same way as the small set does. Oil-pressure governors have been adopted as being much more sensitive and more reliable than any others, their power transmitting agent being at the same time their lubricating agent. Moreover, with oil-pressure governors, energy can be easily stored.

To read the oil pressure, gauges are fitted on each governor, and for indicating the speed, each set has a tachometer. As regards the fall, both head and tail races are connected to a water level recorder which traces on a daily chart the head under which the turbines are working.

The question of the choice of generators, whether D.C. or A.C., was given careful consideration. With D.C. generators the turbines could have been designed to run with varying speed, thus working with the same efficiency under varying heads, but such an arrangement is complicated and, moreover, it was found that the transformation of D.C. into A.C., as required by the transmission line, would have necessitated an expensive motor-generator set. A.C. generators were therefore adopted, and are of the three-phase, 50-cycle type working at a terminal pressure of 6600/7500 volts.

The large alternator has been designed for 675 KVA. (540 KW. at ·8 power factor), and runs at 300 R.P.M. The small one runs at

FIG. 6. THE MAIN SWITCHBOARD.

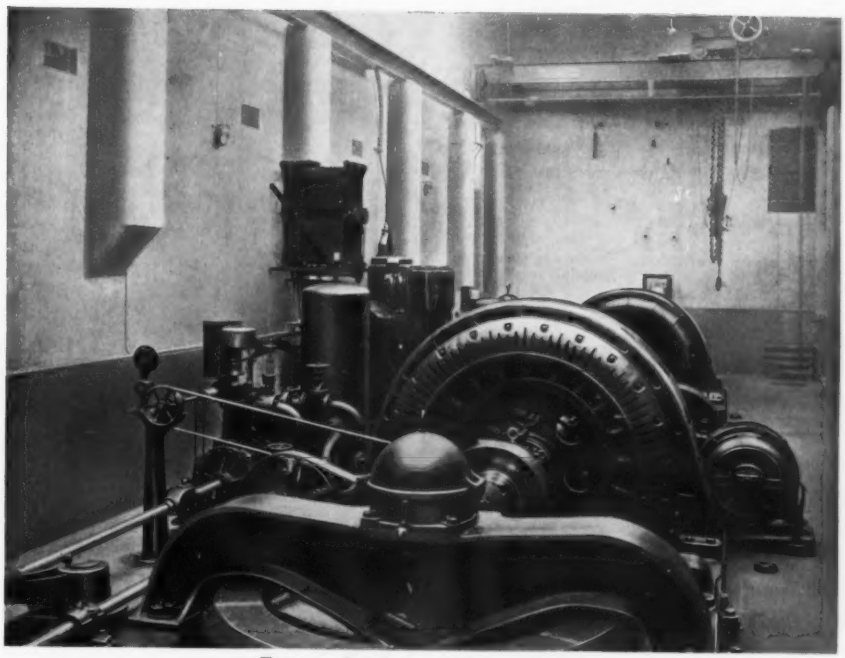
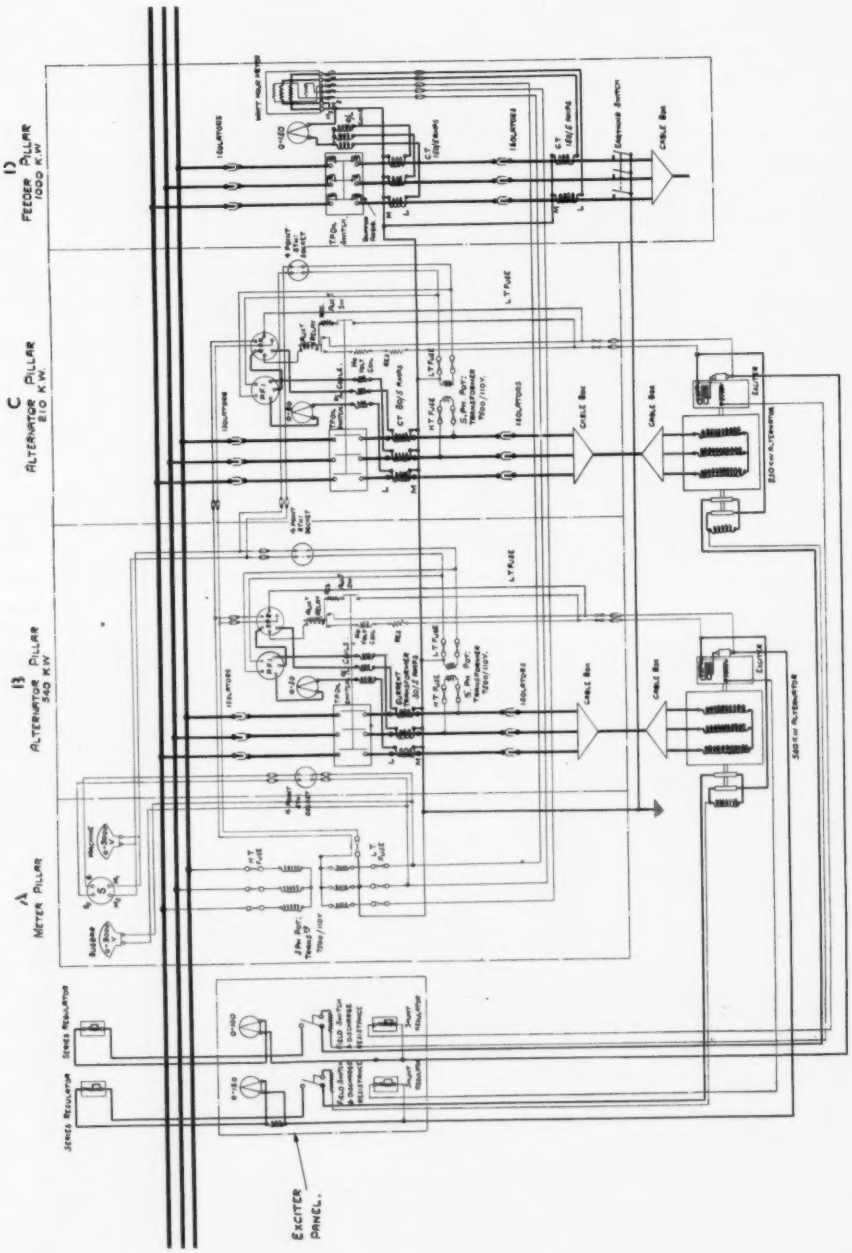
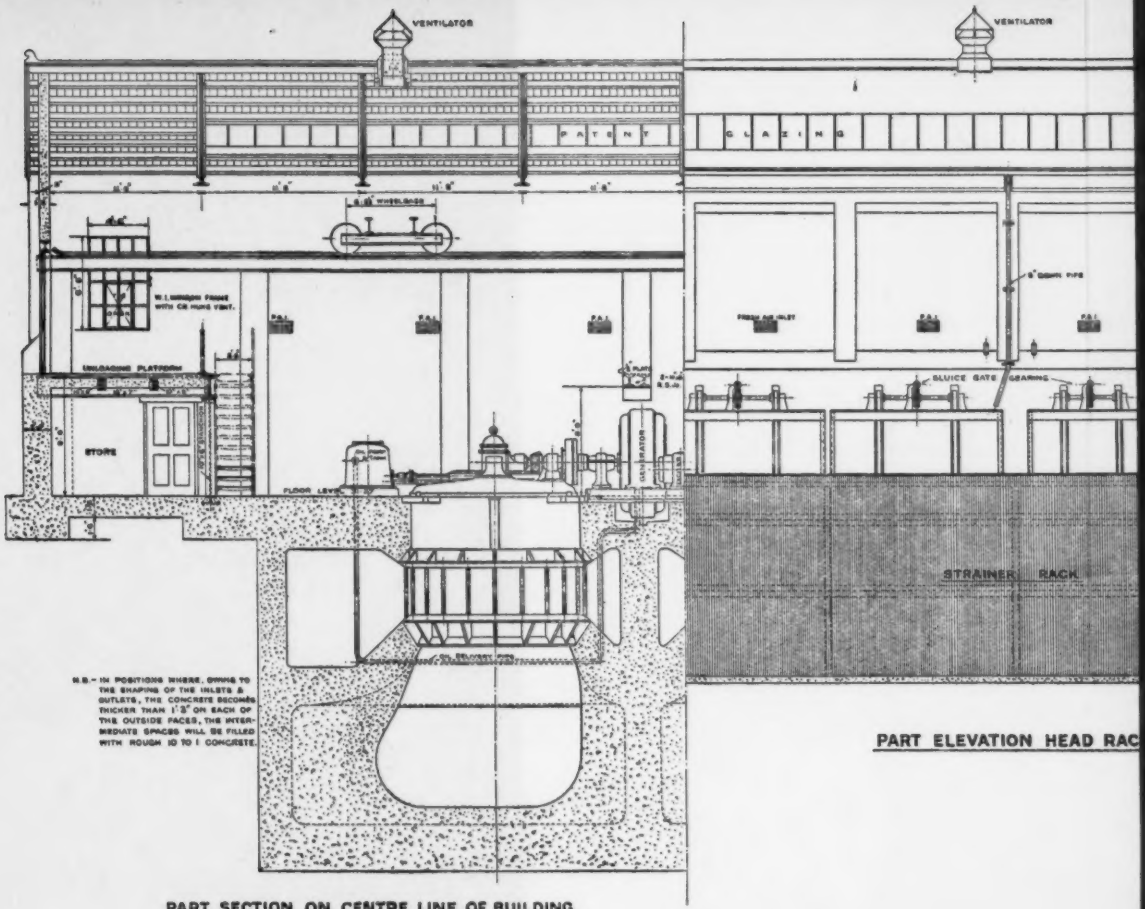


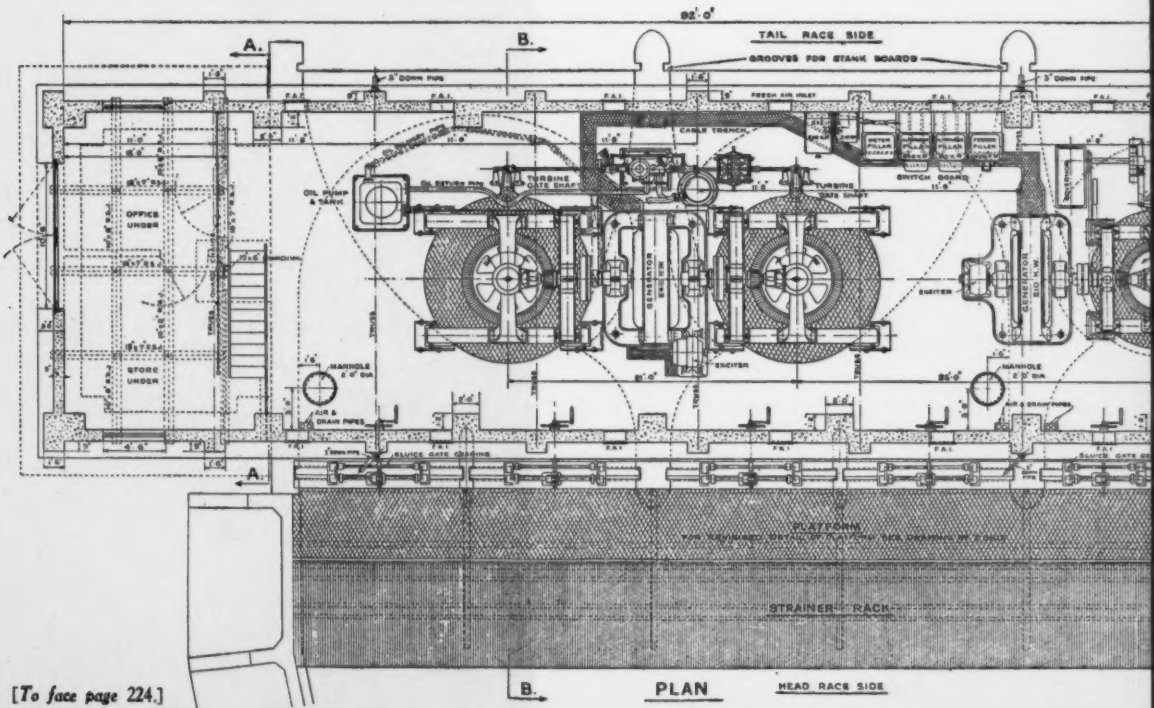
FIG. 7. INTERIOR OF POWER HOUSE.


A
METER PILLAR
B
ALTERNATOR PILLAR
340 K.W.
C
ALTERNATOR PILLAR
810 K.W.
D
FEEDER PILLAR
1000 K.W.
EXCITER PANEL.
SERIES REGULATOR
SERIES REGULATOR
CABLE Box
CABLE Box
CABLE Box
ISOLATORS
ISOLATORS
ISOLATORS
L.T. FUSE
L.T. FUSE
L.T. FUSE
H.T. FUSE
CT Boys Amps
CT 600/5 Amps
3 Pole Air Break
3 Pole Air Break
3 Pole Air Break
Earthing Switch
Earthing Switch
Earthing Switch
Shunt Resistance
Shunt Resistance
Field Switch & Discharge Resistance
Field Switch & Discharge Resistance
Shunt Resistance
Shunt Resistance
Shunt


VENTILATOR
PATENT
GLAZING
VENTILATOR
STORE
UNLOADING PLATFORM
FLOOR LEVEL
SLUICE GATE GEARING
STRAINER RACK
N.B. – IN POSITIONS WHERE, OWING TO THE SHAPING OF THE INLETS & OUTLETS, THE CONCRETE BECOMES THICKER THAN 1'3" ON EACH OF THE OUTSIDE FACES, THE INTERMEDIATE SPACES WILL BE FILLED WITH ROUGH 10 TO 1 CONCRETE.

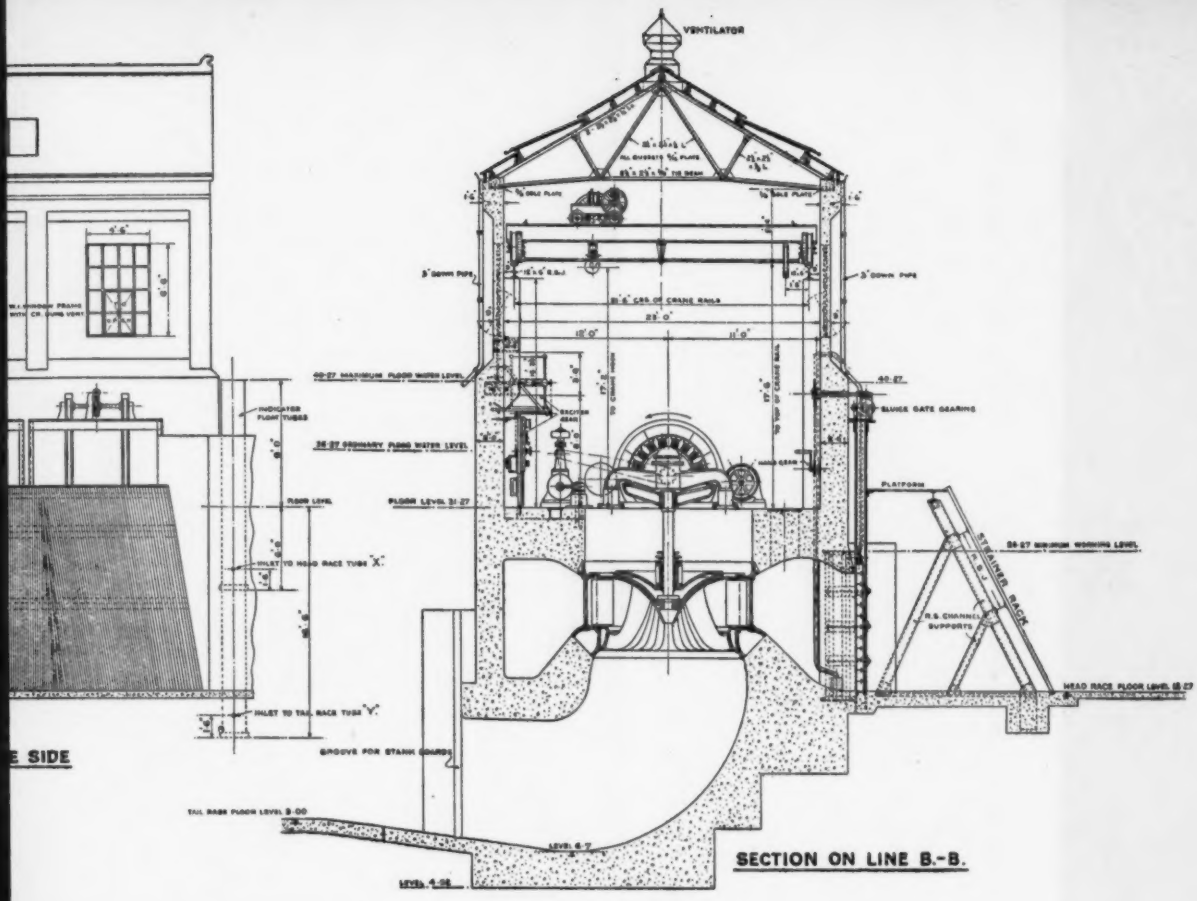
PART ELEVATION HEAD RAC

PART SECTION ON CENTRE LINE OF BUILDING



PLAN

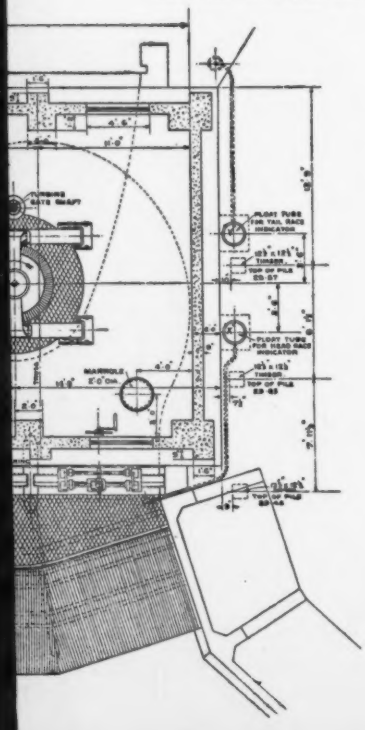
[To face page 224.]

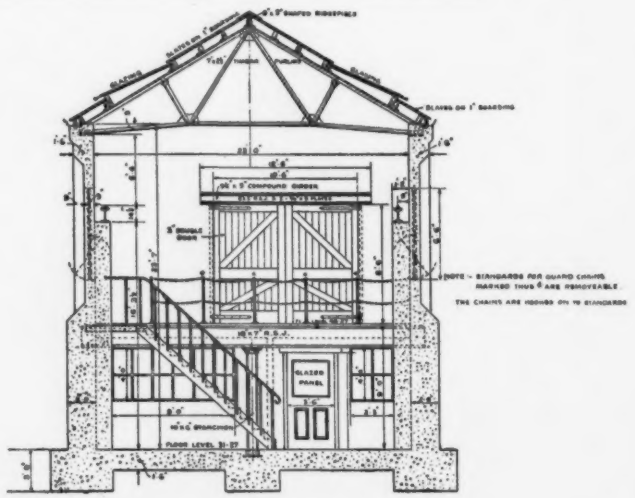


E SIDE

SECTION ON LINE B.-B.

ORDNANCE DATUM LEVEL 0·00





SECTION ON LINE A.-A.

GENERAL ARRANGEMENT OF LINTON LOCK HYDRO-ELECTRIC POWER STATION.

[*The English Electric Journal, Vol. II., No. 5.*]

375 R.P.M. and is designed for 262·5 KVA. (210 KW. at 0·8 power factor). Both generators can withstand the runaway speed of the turbines, which is about 1·9 times their normal speed.

The full load efficiency of the generators is about 94 per cent ; taking 80 per cent. as the average efficiency for the turbines and allowing 2 per cent. losses in the bevel gears, the overall efficiency of the power station is, therefore, about 74 per cent.

The switchboard for controlling the two generators and one feeder is of The English Electric Company's standard SXC cast-iron draw-out pillar type, and is illustrated in Fig. 6 ; a complete diagram of connections is shown in Fig. 8. This class of board is particularly suitable for a station of the kind in question, as it combines a very high degree of safety with extreme compactness. Each pillar consists of two main portions, a stationary portion with supports and the sliding carriage carrying the oil switch, trip coils, instruments, etc. Isolating devices are arranged so that by withdrawing the sliding carriage the oil switch and other apparatus is entirely isolated from all live parts and can be inspected without danger of accidental contact.

The oil switches are of the hand-operated free handle type with the " English Electric " patented spring tank attachment in which the tanks are attached to the top by means of a spring suspension device. The usual air cushion above the oil level, a fruitful source of explosion in many switches, is entirely omitted and care is taken to eliminate all air pockets from this space ; thus the gases caused by the arc when breaking current cannot mix with air and form an explosive mixture inside the switch. The level of the oil extends upwards into a narrow space enclosed by the rim of the oil vessel and the joint is made sufficiently tight to prevent oil splashing over accidentally, but is not intended to be gastight. Any momentary pressure, therefore, caused by breaking a heavy overload current is thus relieved through the medium of the spring suspension device and at the same time any small amounts of gas are able to pass upwards and escape under the flange of the cover.

All live parts are completely enclosed and the pillars are fully interlocked in order to render them fool-proof. It is not possible to withdraw the carriage unless the switch is in the " off " position and the carriage cannot be pushed into contact with the live conductors except with the switch tripped and the oil tank and top cover in position. The oil tank and cover can only be removed when the carriage is withdrawn and is consequently dead, thus affording complete protection from accidental contact with live conductors. Protection is afforded to the generators by three overload coils and a reverse power relay for each machine, operating through an auxiliary relay on a low voltage trip coil energized by the individual exciter of the machine. Protection of the feeders is by simple overload coils. The feeder oil switches are fitted with buffer resistances and charging contacts and a special earthing switch is provided for earthing the cables.

A similar non-draw-out pillar matching up with the remainder of the board carries the synchronizing gear and potential transformers.

Owing to restrictions of space the exciter gear is accommodated on a separate flat-back panel mounted on the wall adjacent to the switchboard, as seen in the illustration.

Regeneration Tests on Locomotives supplied to Chemins de fer du Midi.

By C. E. FAIRBURN, M.A.

In a previous number of this Journal,* the "English Electric" System of Regenerative Braking for locomotives was outlined and a theory evolved from which working characteristic curves were deduced. This system has now been tried out in practice and has proved to be satisfactory in every way.

The locomotives in question are in service operation in the South of France and the tests recorded in this note were carried out in March of this year in the presence of representatives of the Railway Company and the contractors.

The equipment of these machines consists of four DK.80 motors, each of 350 H.P., with "English Electric" camshaft control, and they work on a direct-current overhead line system at 1,500 volts: Fig. 1, reproduced from the

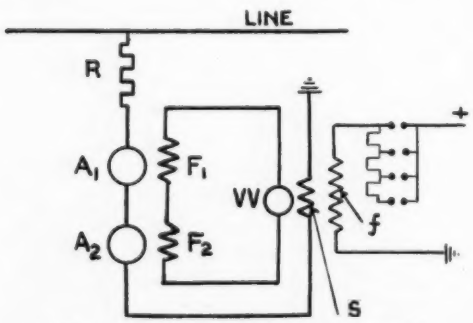


FIG. 1. SKELETON DIAGRAM OF CONNECTIONS.

article cited above, is a skeleton diagram of connections. A_1 and A_2 are the armatures and F_1 and F_2 the fields of the main traction motors; VV is a constant speed variable-voltage generator, the field *f* being excited from a constant voltage low-tension supply. The field of the generator VV is wound with some turns S in series with and carrying the current regenerated by the armatures A_1 and A_2; these turns are such that when current is being regenerated their effect is to oppose the effect of the current in the shunt winding *f*. The current passing through the shunt winding *f* is regulated by the driver from the master controller. A resistance R, which may be called a buffer resistance, is connected in the main circuit. In addition to the apparatus indicated in the diagram, various devices such as an over-voltage relay, a differential relay, etc., are employed to make the system fool-proof.

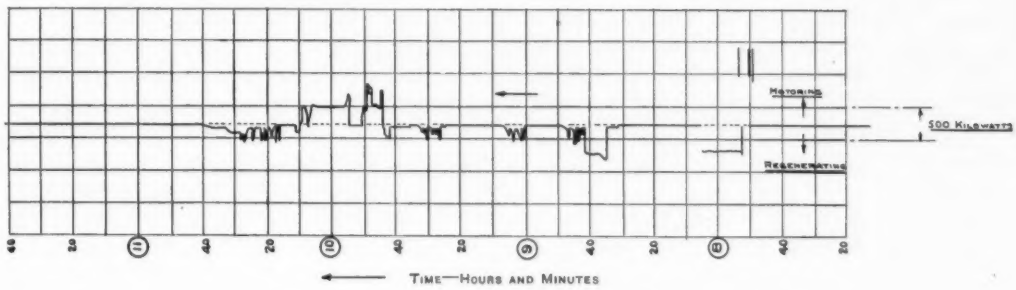
A preliminary run was made on a section of the line between Pau and Lourdes on the 8th March with a view to ensuring that all the connections, instruments, etc., on the locomotive were in order and were conveniently placed for observation. The gradient on this part of the line is quite small, but runs were made with all four motors on a locomotive regenerating, and later with two motors only regenerating. The trailing load in this instance was 300 tons.

The real tests were made on the Tarbes-Toulouse line on the 13th, 14th and 15th March on the gradient from Capvern to Tournai. This gradient is approximately 11 kilometres long and has a practically uniform slope of 30 m.m. per metre (3 per cent.).

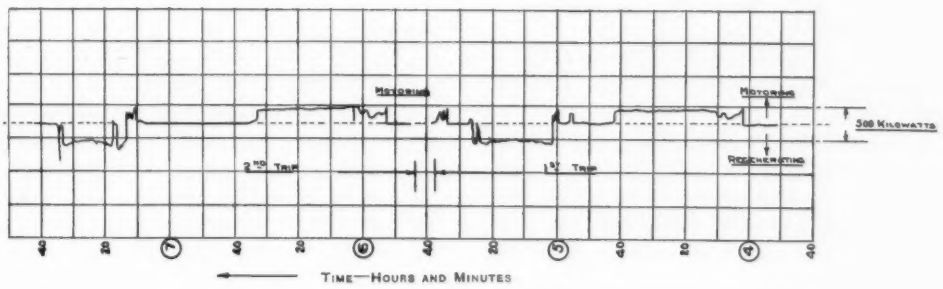
Instruments were arranged to indicate the speed, the regenerated voltage, armature current of the main motors, field current of the main motors and the field current of the variable-voltage generator. Observers were stationed at these instruments and readings were taken simultaneously at a given signal.

The method employed was to manipulate the controller until the train was running at a

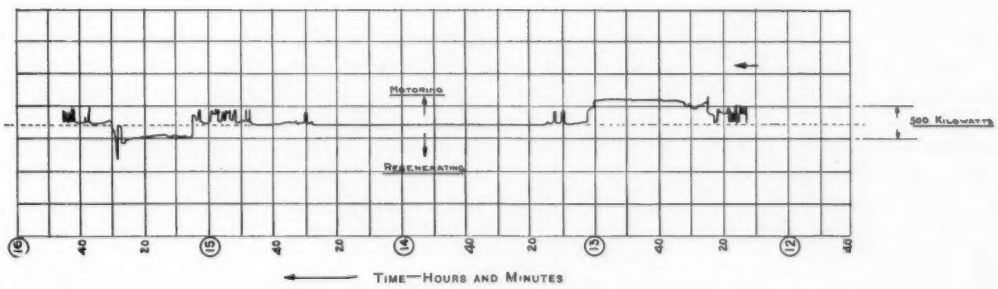
* Volume II., No. 2, April/July, 1922, "An Analysis of Regenerative Braking on Electric Locomotives," by C. E. Fairburn, M.A., and F. A. Harper, M.A.



Test of March 13th.



Tests of March 14th.



Test of March 15th.

FIG 2. ENERGY CHARTS AT SUBSTATION DURING REGENERATION TESTS.

reasonable speed down the gradient, the retardation being effected by the regenerative brake. When the speed, as registered on the speed indicator, was steady two sets of readings were taken with about a minute between the two. The position of the controller handle was then changed, the train allowed to settle down to a steady speed and further readings taken.

The tests made were as follows :—

On the 13th March, a test was run with a trailing load of 200 tons, making a total load, including the locomotive, of 270 tons. It was found possible to regenerate quite satisfactorily, but it was apparent that the actual operation from notch to notch could be improved by altering slightly the values on different notches of the current in the field of the variable-voltage generator.

The necessary adjustments were carried out and on the 14th March two further trips were made.

On the first trip the total weight of the train was 238 tons, made up of the locomotive and 168 tons of trailing load. Regeneration was effected between 19 kms. and 35 kms. per hour on notches ranging from the fourth to the ninth on the controller.

On the second trip the trailing load was 186 tons, making a total load of 256 tons. Regeneration was effected between 19 kms. and 36 kms. per hour and it was found that the train could be controlled within one or two kilometres per hour at any speed between these limits.

On the 15th March the test was made with a light train of 101 tons trailing load, making a total load of 171 tons. Regeneration was effected between 18 kms. per hour and 28·5 kms. per hour.

It was found that the test results corresponded very closely with the theoretical calculations, thus demonstrating satisfactorily that with this system it is possible to foretell with reasonable accuracy how a locomotive will behave when using the regenerative brake.

At the time these tests were carried out the locomotive used was the only one on that section of the line, and charts of the energy used and regenerated were taken at the substation, and are reproduced in Fig. 2. It will be seen that a considerable proportion of energy was regenerated as compared with the energy supplied for taking the train up the gradient. For example, on the 13th March the energy used in hauling the train up the gradient and doing certain shunting was 550 kilowatt-hours, whereas the regenerated energy was 128 kilowatt-hours.

During the first of the two trips on the 14th March a steam locomotive had to make the journey up the gradient at the same time and was coupled to the train, consequently the energy used by the electric locomotive was much smaller than on the first day. The actual motored energy used was 180 kilowatt-hours, whilst the regenerated energy on the return trip with the electric locomotive only, was 115 kilowatt-hours.

The other curves show the proportion of energy regenerated on the first, third and fourth trips of the series.

With the "English Electric" system of regeneration the drivers are able, after a very small amount of instruction, to manipulate the control efficiently. Immediately after the tests had been made, a number of the locomotives were put into service and are operating satisfactorily on gradients ranging between 1 per cent. and 3 per cent.

Progress Notes on "English Electric" Steam Turbine Plant.

The great advantages of the Steam Turbine have brought it to a pre-eminent place as a prime mover; at the same time, however, the design of turbines has continually to be modified and developed to meet the great variety of conditions presented, on the one hand by standards adopted in the days of lower speeds and outputs, and on the other hand by the necessity for constant advance towards higher efficiency and reliability. Satisfactory development of improved designs is rendered possible only by long experience and the careful study of results obtained in practical working, by workshop experiments and by taking advantage of the latest scientific research.

The following notes deal briefly with recent progress along three different lines. The first is concerned with the production of a high-economy turbine for medium outputs at 1,500 R.P.M.; the second with the development of 3,000 R.P.M. turbines for large outputs, for which 1,500 R.P.M. has hitherto been the usual speed. Finally we refer to the highly interesting experiments which have in view the utilization of a boiler pressure of some 3,000 lbs. per square inch.

Fig. 1 illustrates a type of steam turbine which The English Electric Company has recently put on a manufacturing basis to meet a demand which, although somewhat limited, yet is continually being met with for power stations in various parts of the world. Although in Great Britain the frequency adopted for alternating current supply tends, more and more, to become standardized at 50 cycles per second, yet there are many places where 25 cycles was originally selected, and extensions to the generating plant are carried out at that periodicity. For 25 cycles per second the maximum speed of the alternator is 1,500 R.P.M., and at this speed turbines of large output have been standardized which have excellent characteristics; there is, however, a definite demand for such machines of moderate output only, but

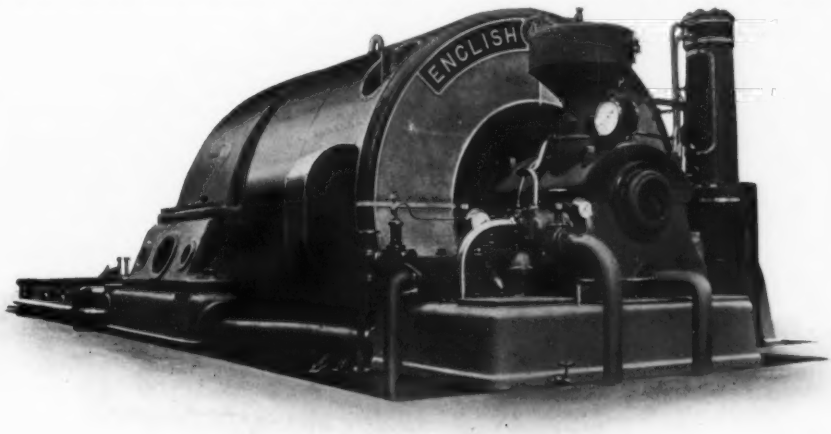


FIG. 1. VIEW ON TEST BED OF 1,500 R.P.M. TURBINE FOR DRIVING 6,500-K.W., 25-CYCLE ALTERNATOR.

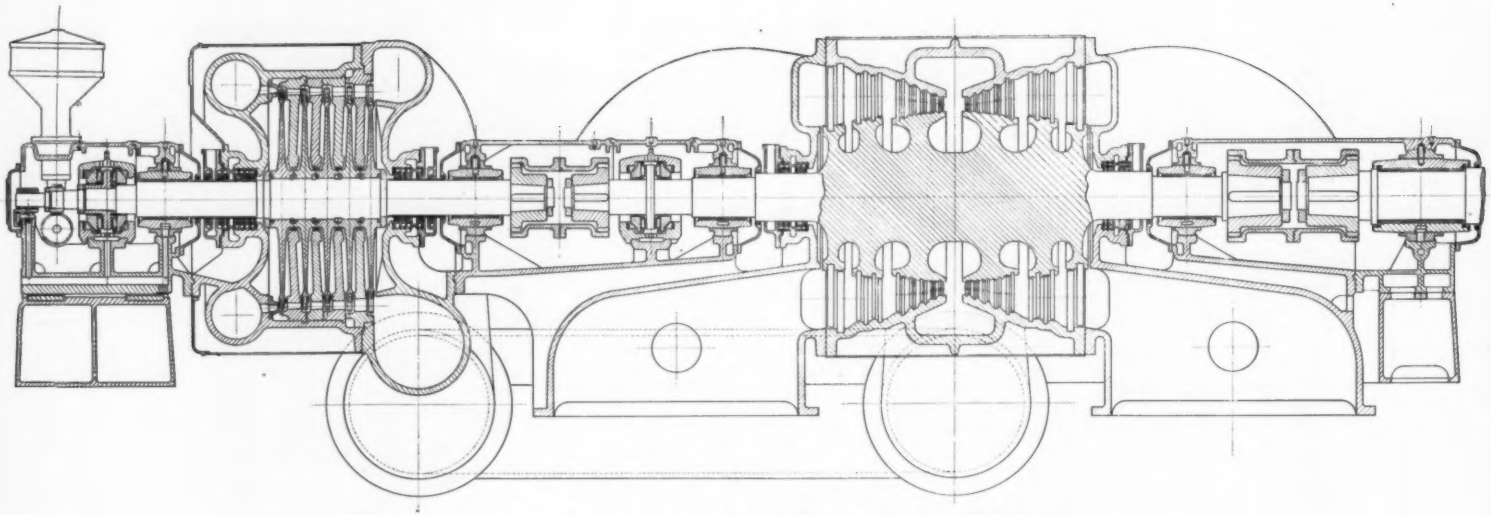


FIG. 2. DIAGRAMMATIC SECTION OF 3,000 R.P.M. TURBINE UNIT FOR LARGE OUTPUTS.

with the high economy associated with 3,000 R.P.M. units. Where really high efficiencies are called for in 1,500 R.P.M. turbines of moderate output, certain problems arise which are not altogether easy of solution, but this Company has now successfully tried out a number of the new machines and is prepared to supply sizes as small as 5,000 KW., which are designed for economies practically as high as can be obtained on machines of much larger output and higher speeds.

The turbine shown in Fig. 1 is for a set having an output of 6,500 KW. at 1,500 R.P.M., and has one velocity stage and eleven impulse stages. All parts which are exposed to high pressure steam are of steel, and particular care has been exercised in the design to avoid any danger of distortion of the casing due to expansion; the weight of the turbine itself is taken by the longitudinal feet at each side which can be seen in the illustration, and the weight is carried in such a manner that all expansion takes place from the centre. The steam and exhaust end bearing pedestals are separate from the main casting—a construction which has been found in practice to result in complete freedom from expansion trouble.

Particular care has been devoted to making all parts self-contained, automatically lubricated and extremely easy to dismantle; as one example of this the arrangement of the governor may be referred to. After removing its outer case, the governor itself can be lifted away completely by loosening only two nuts, and, moreover, this can be done without affecting the adjustment, so that when the governor is put back the turbine will govern at exactly the same speed as before. The importance of this will be fully realized by engineers who have had to make this adjustment on turbines of a different design, where, after dismantling the governor for cleaning, it has been necessary to spend perhaps several hours making modifications in the speed regulating adjustments before the plant was again fit to go on load.

The design embodies all the latest improvements and, as the view shows, the steam end is particularly simple and workmanlike. In place of the old-fashioned reciprocating auxiliary oil pump an extremely neat arrangement is fitted, consisting of a small vertical spindle steam turbine and centrifugal pump; in the illustration the casing of this turbine appears above the bedplate on the left hand side. This auxiliary oil pump starts up automatically in the event of the main oil circulation failing, and is also used to flood the bearings before starting.

An entirely different machine is shown in the sectional drawing of Fig. 2, which represents a type of turbine which has been developed for large outputs at the high speed of 3,000 R.P.M. It will be seen that the principal feature of the design lies in the use of two casings, one a high-pressure turbine of the impulse type, the other a low-pressure turbine on the reaction principle.

That a low-pressure turbine of the design shown is extremely satisfactory and economical in operation is now admitted, and The English Electric Company, owing to its association with the pioneers of this type of turbine, Messrs. C. A. Parsons & Co., Ltd., has every confidence in recommending units constructed on these lines.

Referring to the low-pressure turbine, it will be seen from the illustration that the steam enters at the centre of the casing, passes outwards in both directions through symmetrical sets of blades and then down to the condenser. In this way complete balance is obtained as regards end pressure, so that no dummy pistons or other special balancing devices are necessary.

Looking now at the high-pressure end, the first thing that will strike the reader is the relatively small size of the turbine, both in length and diameter, and it will be obvious that a compact design such as this is particularly well suited to meet satisfactorily the modern developments of high-pressure and high-temperature steam. All the main parts of this turbine are of steel, and the construction, generally, embodies all the special features which have proved so satisfactory in "English

Electric" turbines of other types; although it forms part of a unit of very large output, the high-pressure portion involves no engineering problems of a more serious nature than those encountered every day in the design of 2,000 KW. or 3,000 KW. turbines for the same speed. In no part which runs at a high peripheral speed, is there any necessity for a fine clearance, and under modern conditions all the steam used in this turbine will be above the saturation point, so that no blade corrosion is to be feared.

The English Electric Company is prepared to supply turbines of this type up to sizes capable of giving a continuous output of 20,000 KW. The precise outputs which can be dealt with depend on a number of conditions, such as the steam pressure, superheat and vacuum, but very high economies can be guaranteed up to the size mentioned above. The Company is also prepared to supply and fully to guarantee alternators of the large size and output which are required for coupling to turbines of this high speed. The same remark applies to the necessary condensing plant.

A glance at the illustration will show the Michell thrust block, and beyond this the worm driving the governor gear. It is worth noting that this worm is not overhung, but that the shaft carrying it has a bearing on each side. Flexible couplings are provided both between the high-pressure turbine and the low-pressure turbine, and also between the low-pressure turbine and alternator. This, of course, adds somewhat to the length of the plant, but in a machine of this size and output the advantages are a complete compensation for the extra length and cost.

Some interest has been taken recently by the press of America and this country, in certain investigations which have been undertaken by The English Electric Company in the direction of much higher steam pressures than have hitherto been customary or even contemplated. The Company, in association with the Benson Engineering Co., Ltd. of London, is at the present time making experiments in the generation and utilization of steam at pressures between 1,500 and 3,000 lbs. per sq. in. It is too early yet to speak of any results, but it may be stated that if it is found possible to overcome the technical difficulties, there is a quite definite saving in the use of such pressures. The Benson Engineering Company possesses patents for a steam boiler which will generate steam at the so-called "critical" point. At this point, which is in the neighbourhood of 3,200 lbs. per sq. in., water possesses the property of passing quietly into a gaseous condition, the reason for this being that the water possesses no latent heat in making the change. It is proposed to throttle the steam down from this very high pressure to a pressure of about 1,500 lbs. per sq. in., and the pending experiments are designed with a view to solving problems not only in generating the steam, but in its utilization in the steam turbine. The turbine which The English Electric Company is constructing will have an output of about 350 KW., and will run at a speed of about 25,000 R.P.M. After being expanded in this turbine the steam will be reheated and then passed at a pressure of about 250 lbs. per sq. in. to a turbine which, relatively speaking, may be described as the low-pressure turbine. The problems involved in the design of this turbine are within present practice, and it will not therefore be constructed until further knowledge has been obtained on the high-pressure turbine.

The total output of the unit for which the high-pressure turbine only is being built, will be about 1,000 KW., and it is interesting to note that the steam for this output will be conveyed from the boiler to the high-pressure turbine in a steam pipe having a bore of only $2\frac{1}{8}$ inches, whilst the equivalent diameter of the exhaust is $3\frac{1}{4}$ inches.

Electricity in the Portland Cement Industry.

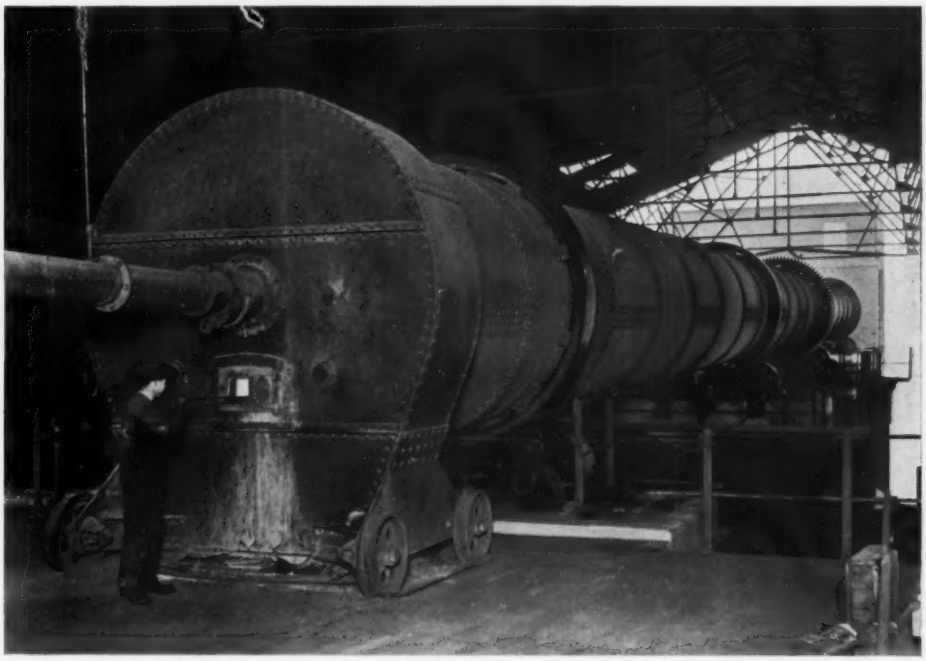


FIG. 1. FIRING END OF ROTARY KILN SHOWING METHOD OF SUPPORT AND DRIVING RING.

Electricity has been an important factor in the development of the Portland Cement industry, and the advantages of adopting this form of power have now been so fully confirmed by experience that its use is practically universal. The relatively large amount of power taken by the various units of the plant and their scattered distribution cause the transmission losses with any form of mechanical drive to be unduly high, especially if the plant has to be run below its full capacity owing to prevailing market conditions. The commercial success of a cement plant at the present day depends not only upon the technical perfection of the layout and individual processes, but also upon the cost of power being reduced to a minimum by operating the various machines at their most economical outputs during the daytime and working from storage during the night. Individual drive by electric motor not only reduces the power item of cost by saving the greater part of the friction losses, but gives flexibility for adjustment of the various machines so that the most economical speed can be found and maintained; at the same time it allows any portion of the plant to be operated independently of the remainder, either during completion of a new mill or subsequently. Added to this is the ease with which the power consumption of any machine can be ascertained, so that the effect of alteration to its speed, adjustment or mode of use can be examined in a perfectly definite manner.

Since the operation of a modern Cement Works is carried on night and day practically without intermission throughout the year, it is clear that the average load factor will be high, and therefore the load is a desirable one from the supply company's point of view, and one that can be met at a low figure whether the source of supply is a public or private generating plant.

speed independent of voltage or temperature fluctuations, are well suited to meet the requirements, and the majority of cement plant installations are carried out with this type of machine.

The production of Portland cement consists essentially in bringing about a chemical combination, by firing, between siliceous and calcareous bases, which may either occur in a

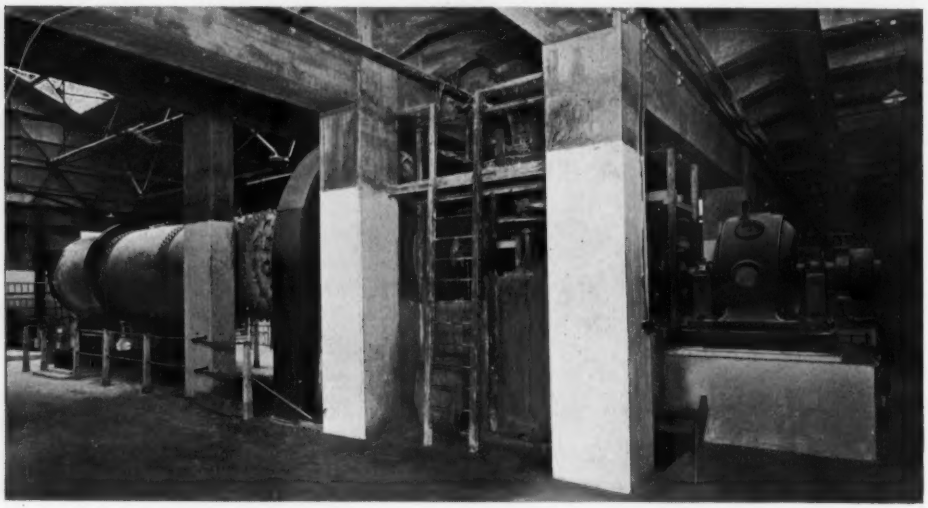


FIG. 2. COMBINATION TUBE MILL AND 300 H.P. DRIVING MOTOR.

Apart from the continuity of service which is demanded, the special conditions which have to be taken into account are the presence of gritty dust or moisture in some portions of the plant. Most of the machines employed are of a heavy nature requiring gear, chain or belt drive, and in many of them very large masses of material have to be accelerated, so that considerable starting torque is required; at the same time the normal load is usually a steady one and the speed variations required are within small limits.

From the above considerations it follows that alternating-current motors of the induction type, owing to their simple construction, the absence of a commutator and their constancy of

natural aggregate or be artifically compounded from clay and chalk or limestone. As intimate and uniform admixture of the raw materials is necessary to their thorough combination, and extreme fineness of the product is a measure of its quality, it follows that mixing and grinding machinery plays an important part in the process.

Amongst a number of cement plants which have been equipped electrically by The English Electric Company, two recent examples, one in this country and the other in India, will now be described as illustrative of modern practice.

In both of these installations the motors are of The English Electric Company's standard type, of very substantial construction throughout;

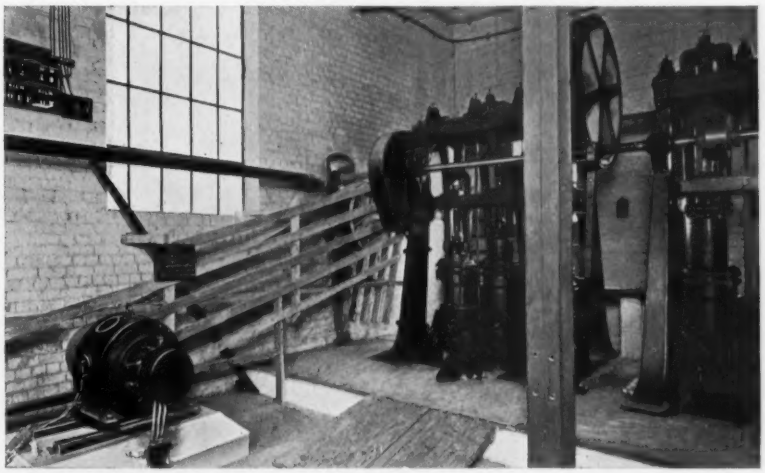


FIG. 3. DRIVING END OF BANK OF RAM PUMPS FOR SLURRY.

the bearings and shafts are of particularly massive design in order to provide for the heavy starting torques and long hours of running ; the windings also are generously proportioned and suitably insulated to withstand the dusty or moist atmosphere prevalent in certain parts of the mill.

Where motors of the slipring type are employed, the slipring gear is completely enclosed in a metal casing, and in some cases, as will be seen from the illustrations, the larger motors are installed in separate compartments isolated from the driven machinery.

The Works of the Humber Portland Cement Co., Ltd., at Melton, near Hull, were completed in 1921, and are situated near the River Humber, on the banks of which occur the deposits of alluvial clay used in the process ; the other ingredient is obtained in the form of indurated chalk from a quarry 1½ miles distant. The Works were laid out by the consulting engineers, Messrs. Maxted and Knott of Hull. On their advice it was decided not to install generating plant but to obtain power from the Hull Corporation by whom it is transmitted at 22,000 volts, 3-phase, 50 cycles, and transformed in two substations—one at the Works, the other at the quarry—to the motor supply pressure of 400 volts ; the power consumption amounts to some 10 millions of units per annum.

FIG. 4. SLURRY MIXING TANK SHOWING STIRRER GEAR.

FIG. 5. GENERAL VIEW OF MIXING TANK, BUCKET-WHEEL AND WASH MILLS WITH STORAGE TANKS IN FOREGROUND.

The whole of the cable was supplied by Messrs. Siemens Brothers & Co., Ltd.

After being dug out by a steam navvy the chalk is dealt with by a gyratory crusher driven by a 150 H.P. motor. By screening the product and passing the tailings to a small jaw-type crusher, the chalk is sufficiently fine to pass to the combination tube mills, of which there are two with space for a third. Fig. 2 shows one of these machines driven by a 300 H.P. motor; the rotating tube is 6 ft. in diameter and 32 ft. long, and is divided into three sections, of which two are charged with steel balls and the third with flint pebbles. Water is added to the chalk as it enters this mill, and the resulting "slurry" is then pumped through a pipe-line to the factory. For this purpose, electrically-driven three-throw pumps of specially heavy construction are used, similar to those shown in Fig. 3. By this means chalk stone is conveyed at the rate of about 4,500 tons per week, exclusive of the added water. The "slurry" is discharged into a circular mixing tank (Figs. 4 and 5), 66 ft. across by 11 ft. deep, in which there is mounted a stirring arrangement consisting of a horizontal lattice girder pivotted on a pillar rising from the centre of the tank and fitted with four sets of stirring arms. As will be seen from the illustrations, these arms are driven by bevel gearing from a horizontal shaft which passes through a central housing containing the 25 H.P. squirrel-cage driving motor. The reaction of the rotating arms against the slurry causes the whole girder to revolve so that the mass is thoroughly stirred. Current is conveyed to the motor through sliprings mounted on top of the hut, and Fig. 4 shows the span-wires and cables; the control gear is situated in a building adjacent to the tank.

The slurry is taken from the mixing tank by a 28-ft. diameter bucket-wheel seen in the background of Fig. 5, and flows through motor-driven automatic measuring apparatus to the Wash Mills, which are tanks some 20 ft across in which the clay is added and mixed by revolving horizontal "harrows." The mixture is then strained to remove coarse matter and

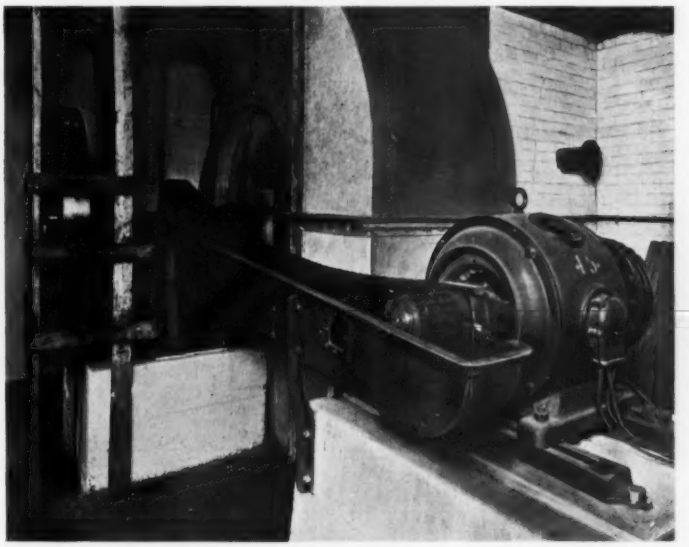


FIG. 6. INDUCED-DRAUGHT FAN AND DRIVE.

passes to further mixing tanks which also contain stirrers and serve as storage tanks for the night. The material, however, is not yet fine enough for the firing process and is therefore dealt with in two tube mills similar to those previously described and illustrated in Fig. 2, but in this case driven by 75 H.P. motors. The slurry is now ready for the firing, but owing to the great importance of keeping the kilns running continuously, a large storage capacity is provided at this stage in the form of the six tanks seen in Fig. 5, each of which hold about 1,000 tons. These tanks are provided with a system of pneumatic agitation to prevent settling. For pumping the slurry to the tanks and kilns, three sets of three-throw plunger pumps are provided, and one of these and the 30 H.P. motor which drives them all are seen in Fig. 3. One pump delivers from the tube mills to the tanks, the second from the tanks to the kiln, and the third is a spare for either purpose.

The rotary kilns are the central feature of the plant, and to their correct and continuous operation all other items are subservient. Fig. 1 shows one of the kilns, which consists of a steel tube 9 ft. in diameter by 200 ft. long, lined with fire brick and sloping downwards at a small angle from the feed end to the furnace end.

As the whole of the firing operations are controlled from the delivery or furnace end of the kiln, it is usual to assemble all the motor

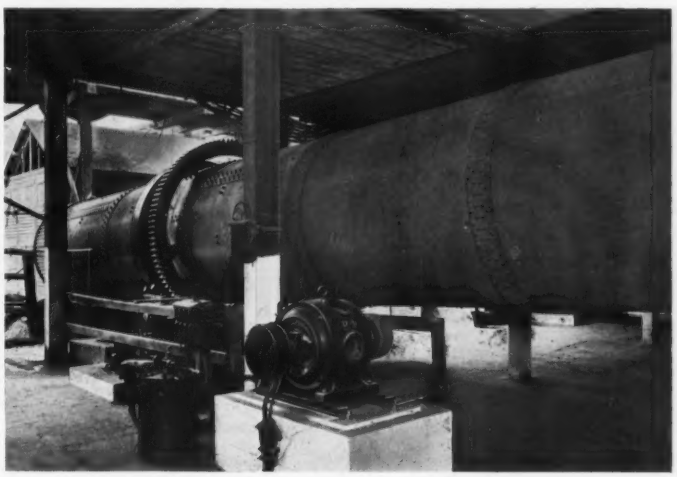


FIG. 7. CLINKER COOLER, MOTOR AND CONTROL GEAR.

controls for the kiln and its auxiliaries at this point, and for this reason the main driving motor is usually placed as near to this end as is consistent with avoiding the intense heat of the furnace itself. The slurry is fed in from the top end by a series of spoons or scoops which dip into a tank, and this spoon feeder is driven by a 1½ H.P. variable-speed motor, so that the quantity of slurry fed in can be adjusted as may be necessary.

The kiln itself is driven by a 75 H.P. variable-speed motor, and normally takes 90 seconds for a complete revolution. It can, however, be slowed down to 130 seconds or can be speeded up slightly. Under the action of rotation and gravity the slurry gradually passes to the lower end of the kiln at which the burning zone is situated. This end of the kiln is closed in by a firing hood in the centre of which is the fuel jet supplied by a firing fan, driven by a 30 H.P. variable-speed motor, with hot air drawn through the cooler described later. Very finely powdered coal is introduced into the stream of air by a spiral feeder driven by a variable-speed motor rated at 5 H.P. The jet ignites immediately on entering the kiln and maintains the material at this end of the kiln at a white heat. The hot gases passing through the kiln dry the slurry travelling in the opposite direction, and as it passes through the burning zone the mixture becomes a chemical combination. The clinker, as the material is now called, falls from the bottom end of the kiln in the form of irregularly shaped pieces somewhat similar in appearance to gravel.

It will be seen that the problem of driving and supporting the kiln is a somewhat special one since it is subject to considerable expansion and contraction, as well as warping, due to the heat. The weight of the kiln is taken at intervals by cast steel tyres which run on water-cooled rollers. These tyres are attached to the kiln by cast steel chairs which allow the kiln to expand or to warp slightly without distorting the rings. The drive from the 75 H.P. variable-speed motor is first through a belt and then through a train of reduction

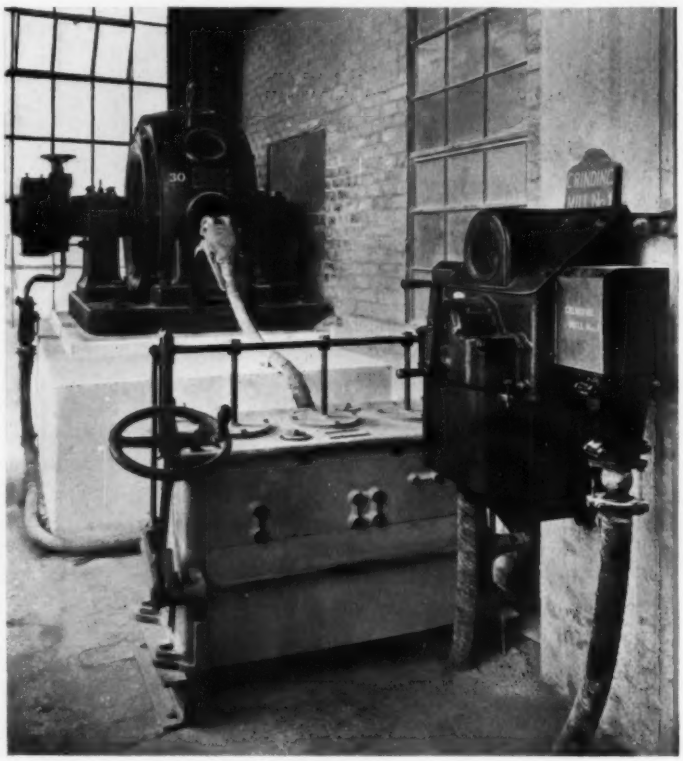


FIG. 8. 400 H.P. SLIPRING INDUCTION MOTOR AND CONTROL GEAR FOR DRIVING ONE OF THE CLINKER GRINDING MILLS.

gearing, the last stage of which is a toothed ring surrounding the kiln as can be seen from Fig. 1. Here again, flexibility has to be provided as in the case of the tyres supporting the weight of the kiln.

Induced draught is used for the kilns and for this purpose a fan is provided at the base of the chimney, driven by silent chain from a 30 H.P. variable-speed motor. The motor and fan are shown in Fig. 6, which also clearly shows the chain drive.

In connection with the control gear there is an interesting system of interlocking; if for any reason the induced draught fan were to stop there would be grave risk of an accumulation at the top end of the kiln of explosive gases, which would be ignited by the heat from the burning zone. The control gear of the induced draught fan is therefore interlocked with that of the coal feed and firing fan in such a way that both these latter motors will shut down immediately the circuit breaker controlling the induced draught fan motor opens.

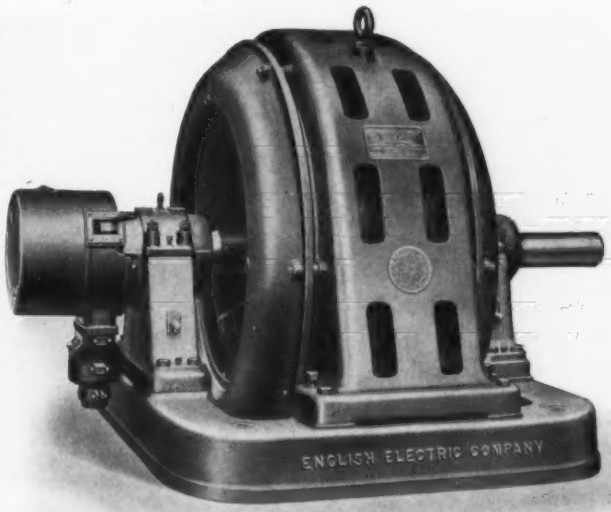


FIG. 9. 550 H.P. 250 R.P.M. INDUCTION MOTOR RECENTLY INSTALLED FOR DRIVING NO. 3 GRINDING MILL.

The coal dust for firing the kiln is usually made from bituminous slack, but the coal plant has been designed to use any coal which may be available. The coal passes through a set of coal crushing apparatus capable of dealing with about 30 tons per hour, crushing into one inch cubes. It then passes to a group of ferro-concrete silos holding about 900 tons, and from here through the rotary coal dryers which are separately fired, and is then ground by combination tube mills similar to those previously described. These tube mills are driven by 150 H.P. motors. From the mills the coal is delivered to two steel plate hoppers in the kiln house, each containing about six hours' supply of powdered coal for one kiln. There is also a ferro-concrete silo here capable of holding about 300 tons of powdered coal for use at week-ends, and to provide against the stoppage of the kiln in the event of any part of the coal grinding apparatus being out of operation. Provision is made to keep the powdered coal in movement so as to avoid spontaneous combustion. The powdered coal from the hoppers is fed by spiral conveyors to the air outlet of the firing fans.

The clinker from the rotary kiln is discharged into a rotary cooler which is very similar in appearance to the kiln, but on a smaller scale. Channel irons are provided along the length of the cooler which raise the clinker to the top and then drop it across the draught of air passing along the cooler. This air, after taking up the heat from the clinker, is used as mentioned above for firing the kiln. Fig. 7 shows the cooler with the 20 H.P. motor driving it. In this illustration can also be seen the tangential steel plate drive which gives the flexibility required on account of the varying temperature of the cooler. A similar device is used for the kilns.

FIG. 10. TELPHER LINE ACROSS THE SONE VALLEY FOR CONVEYING LIMESTONE TO THE JAPLA CEMENT MILLS.

The clinker on leaving the cooler is conveyed either to the cement mills or to a bulk storage ground. For grinding, two combination tube mills were originally installed, each driven by a 400 H.P. motor; a third mill has recently been added, driven by a 550 H.P. motor, of which a view is shown in Fig. 9. This part of the process usually absorbs the greatest amount of power. As clinker is very hard and extreme fineness of the finished cement is aimed at, exceedingly fine grinding is required. The tube mills are similar to those described in connection with the grinding of the chalk. The driving motors, one of which is shown in Fig. 8 with its control gear, are mounted in a separate building. The drive is taken through an iron plate in the wall to a set of cast steel reduction gearing in the mill. Before the grinding a small quantity of gypsum is added to the clinker to adjust the setting time of the cement.

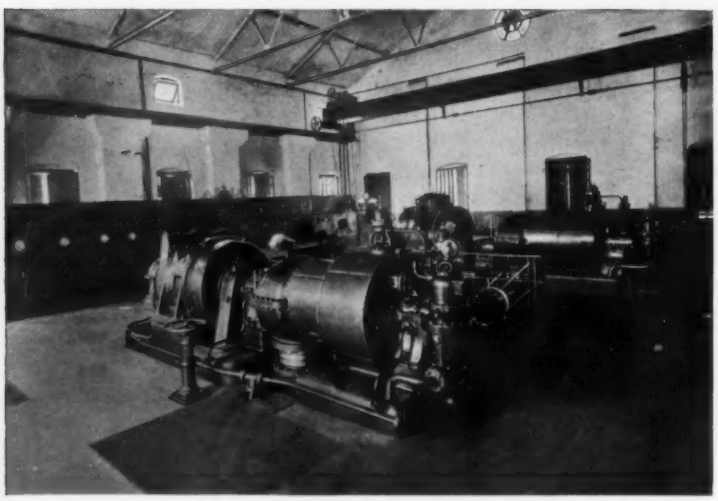


FIG. 11. THE POWER STATION AT JAPLA MILLS.

The finished cement is taken by means of

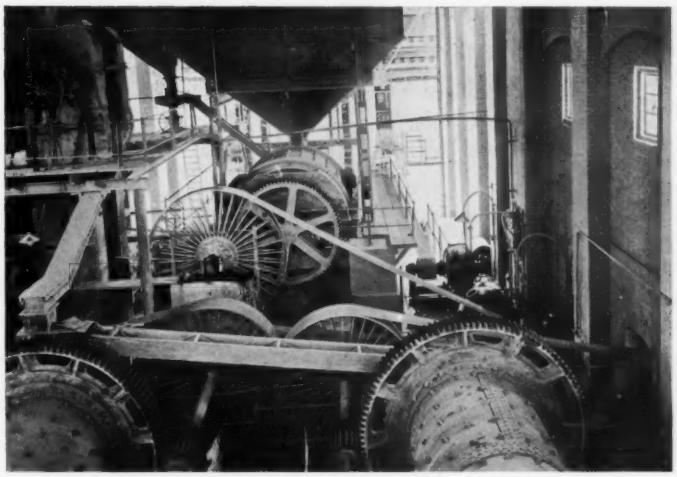


FIG. 12. WET SLURRY MILL AND, IN FOREGROUND, TWO WET TUBE MILLS.

spiral conveyors and elevators to ferro-concrete silos which have a capacity of several thousand tons, and from these is blended and packed into bags by automatic machines, or into casks for export.

There are numerous conveyors of different types throughout the factory which have not been specifically mentioned. The material is not touched by hand from the commencement of the operations until the filled sacks of cement are stacked in the railway trucks for transport to their destination.

In the case of the Humber Portland Cement Company's plant complete provision has been made for the collection of dust from the coal crushing plant, the clinker grinding plant and the sack plant. The dust collectors are of the filter bag type with motor driven exhausting fans. The value of installing dust plant is not only seen in such general ways as the better health of the employees and increased life of machinery, but also in the actual value of the dust recovered, since the dust, being the very finest product of the grinding process, is the most valuable part, both in the case of the coal dust and the finished cement.

The remaining illustrations relate to the Japla Mills of the Associated Portland Cement Manufacturers, one of the recent cement plants in India which have been equipped electrically by The English Electric Company. This mill is situated on the River Sone, in the Province of Bihar and Orissa, and a cable transporter five miles long is used for conveying the limestone across the river from the quarries. In this case the electrical power is generated on the spot by steam turbine plant and is distributed to the motors as three-phase, 50-cycle current at 460/480 volts. The power house contains two "English Electric" turbo-alternators,

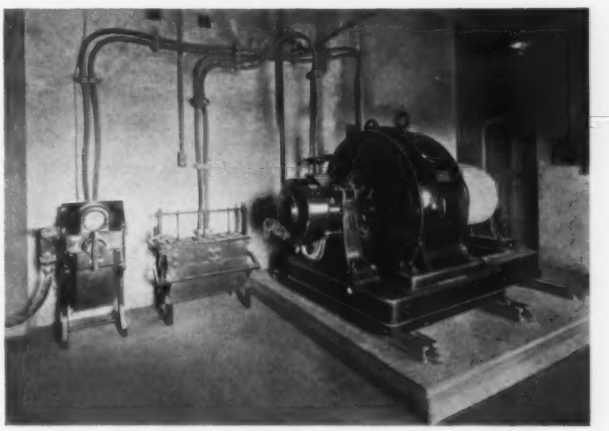


FIG. 13. ONE OF THE 250 H.P. MOTORS FOR DRIVING WET TUBE MILL ILLUSTRATED IN FIG 12.

of 1250 KW. and 500 KW. respectively, and switchgear; the motors are of the Company's three-phase induction type with squirrel-cage or slipring rotor according to the nature of the drive.

There are fifty-six motors in all, ranging from 1½ H.P. to 250 H.P., and with an aggregate capacity of over 2,800 H.P.

Figs. 10 and 11 show respectively the telpher line across the river and the interior of the power station with the main switchboard comprising generator and feeder units; as will be seen, this board is of the sheet metal cubicle type which possesses the advantage of great compactness and safety.

Several interesting features are shown by Fig. 12. The motor in the background is of 150 H.P. and is driving by belt a number of stone crushers which cannot be seen; in front of this motor another of the same size is visible together with its belt drive on to the wet ball

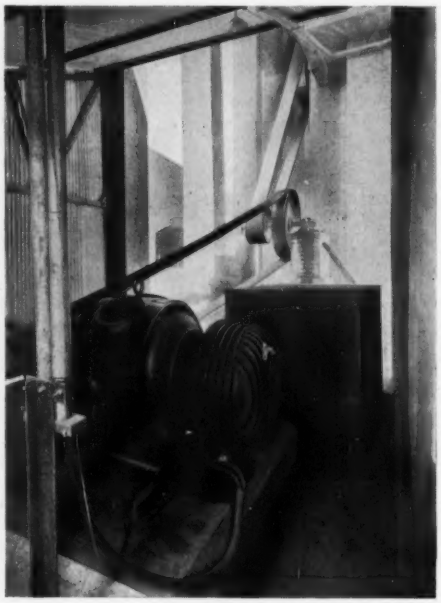


FIG. 14. VARIABLE-SPEED MOTOR, WITH DUST-PROOF SLIPRING COVER, FOR DRIVING ROTARY KILN.

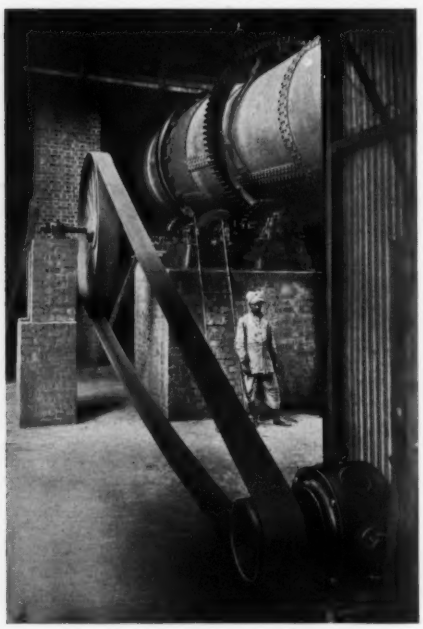


FIG. 15. CLINKER COOLER AND DRIVE.

mill in the centre of the picture. The two machines in the foreground are wet tube mills each driven by a 250 H.P. motor housed in separate rooms beyond the side walls. A view of one of these motors with its main oil-switch pillar and liquid starter is shown in Fig. 13.

The 50 H.P. motor and double-belt reduction in Fig. 14 drive the rotary kiln; this motor is of the variable-speed slipring type and has a massive dustproof slipring box. The clinker cooler with its motor drive is illustrated in Fig. 15, while Fig. 16 shows the coal grinding mill and 150 H.P. motor.

As an example of the numerous small drives for conveyors, etc., Fig. 17 is given and shows two motors driving elevators for handling the finished product. An interesting feature which we have not been able to illustrate but which is commonly found in Indian cement works, is the refrigerating plant. The cement as it comes from the dry mill is warm, due to the

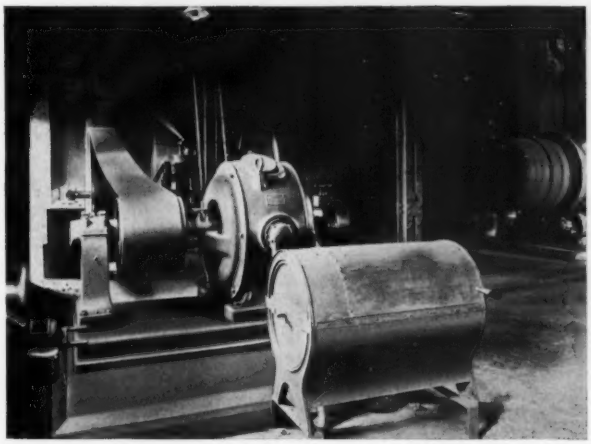


FIG. 16. COAL GRINDING MILL DRIVEN BY 150 H.P. MOTOR.

friction of grinding, but it is not suitable for use until it has been conditioned by being kept at a moderate temperature for a period of several days. In a tropical climate the necessary temperature can only be attained at certain seasons of the year by artificial means and a special refrigerating chamber is provided in which the cement is kept for the period necessary to bring it into proper condition for use. The refrigerator is of the ammonia type and the compressor is driven by a 2½ H.P. motor.

Fig. 18 shows the distribution boards for controlling motors in the dry mill. These are both of the English Electric Company's standard ironclad unit type, that on the left being built up of type SXA. Oil-Break Switch pillars, whilst the smaller board consists of type S.W. Air-Break triple-pole switches mounted on bus-bar chambers. The former controls the dry tube and ball mills, the ropeway, a lighting transformer, etc., and the latter, the motors for various elevators and conveyors, the dust plant and cement bagging plant. The lighting transformer referred to can be seen at the right-hand bottom corner of this illustration. Two very similar switchboards, one of the oil-break type and one of the air-break type, control the coal plant, rotary kiln, slurry mixers and clinker conveying plant. Smaller switchboards of a similar type are also installed in other parts of the factory so that every motor is fed by its individual circuit. A few of the largest motors have individual feeders from the main switchboard, but the majority are fed from the distribution boards.

Water for the process of manufacture as well as for the condensers of the generating plant is pumped from the river by means of pumps driven by vertical shaft motors. These motors are of the squirrel-cage type rated at 80 H.P., and are provided with ball journal and ball footstep bearings. Two of the pumps raise the water to a storage reservoir

FIG. 17. MOTOR-DRIVEN ELEVATORS FOR HANDLING FINISHED CEMENT.

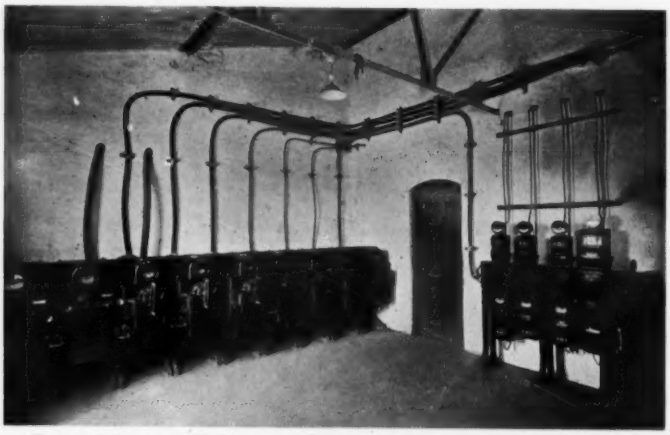
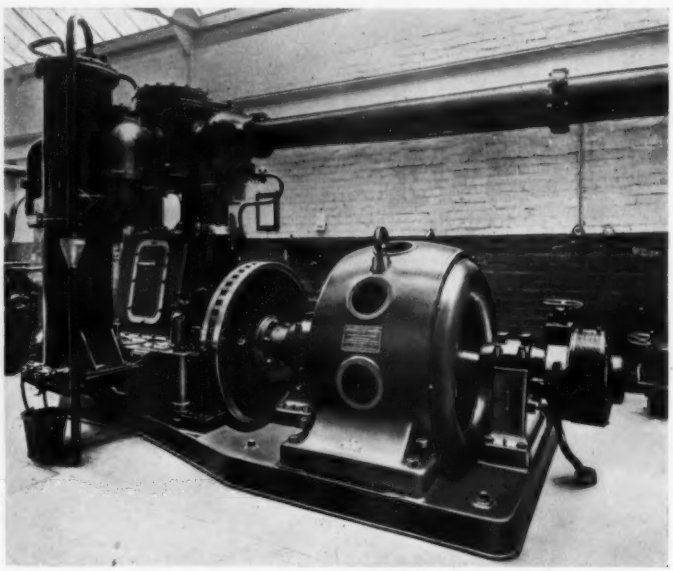


FIG. 18. "ENGLISH ELECTRIC" IRONCLAD UNIT TYPE SWITCHBOARDS CONTROLLING MOTORS AT FINISHING END.

and a third pump of the same size circulates the water from the reservoir through the condensers. There is also a pump driven by a 15 H.P. motor feeding a tank for the water used in the process of manufacture.

Both of the installations referred to in this article have been in full operation for some time, and the electrical plant has fulfilled in the highest degree the expectations of the engineers and others associated with the projects.

ELECTRICALLY-DRIVEN AIR COMPRESSOR IN STEEL WORKS.



The illustration shows a typical steel works Compressor set driven by a 203 H.P. "English Electric" 3-phase, slipring motor running at 300 R.P.M. on a 6,600-volt, 25 cycle supply.

Electric Propulsion of Ships.

By L. ROTHERA, B.Sc., A.M.Inst.C.E.

For many years workers in this country have been advocating the electric propulsion of ships, but the practical application on a large scale of this form of drive has been carried forward by the United States, and there is now available a very considerable amount of data from which a true opinion of the merits of the drive can be formed. The published results show so large a measure of success that the fullest consideration of the problem by shipbuilders and shipowners in this country can no longer be deferred.

There is a tendency on the part of our shipbuilders and owners to consider the electric drive as somewhat in the light of an experiment, but the success which has attended its application to almost every other purpose should induce a predisposition to give its claims full investigation.

In the following article a comparison is made along two lines, the first a Diesel electric drive as compared with the direct Diesel, and the second a steam turbine electric drive in place of the steam turbine and mechanical gear reduction. The failure of mechanical gear to give altogether satisfactory operation lends an added incentive to consideration of the alternative electrical speed reduction.

In this article it is proposed to deal mainly with equipments suitable for two classes of vessels :—

(1). Cargo carriers.

(2). Passenger boats.

Mention is made later of the special application which has been most fully developed in the United States, namely, that for battleship drives.

The cargo boat of the future appears likely to develop on the lines of the internal combustion engine, and in this connection attention may be called to the very great advance that has recently taken place in the number of Diesel-driven ships afloat. In the year 1922, a total of eighty-two ships of over 1,000 tons dead weight capacity were launched or under completion with an aggregate power of practically 232,000 i.h.p., and a total dead weight tonnage of 610,000. This represents an increase of nearly 50 per cent. over the boats under construction the year before, which in its turn was 50 per cent. greater than that of 1920.

Most of the vessels so driven have been built for cargo carrying, but a number of passenger boats are now under construction which will be fitted with this class of engine. The largest is a 20,000 ton liner for the Union Steamship Co., which will be driven by a total of 12,000 h.p. made up in four units.

This development foreshadows the possibility that the slow speed liner of the future, as well as the cargo boat, will use the internal combustion engine, though when very large powers are required the steam turbine will, as at present, remain the prime mover adopted.

It becomes necessary then to contrast the Direct Diesel drive or Steam Turbine drive through gearing with the alternative Diesel Electric or Steam Electric drive, and though at first sight the apparent complication may not appear warranted, yet a closer study shows very marked advantages, which are detailed below. Dealing first with the Diesel Electric as compared with the Direct Diesel, a comparison yields the following results :—

(1). *Space required.* This consideration is of vital importance in the design of a cargo boat, and recently in an actual case a saving in space of no less than 7,000 cubic feet was made by the adoption of the Diesel Electric drive in place of the Direct Diesel. Apart from the actual saving in space, the possibility of putting the motors right aft and eliminating shaft tunnels allows, in many instances, of the adoption of a better design of ship for cargo purposes.

(2). *Reduction in Weight.* It is generally found that the Diesel Electric drive is considerably lighter in weight than the Direct Diesel drive, and in one instance with a total power of 4,200 s.h.p., the Electric drive showed a reduction in weight of 25 per cent. The boat in question was a twin-screw boat, and two generating sets were employed, each supplying one of the propeller motors.

(3). *Ease of Manœuvring.* When Diesel-driven generating sets are employed, direct-current machines would be adopted to avoid difficulties in parallel running, with corresponding D.C. motors for the propellers. With these conditions the speed control of the motors will be on the Ward-Leonard principle, *i.e.*, the speed of the motors will be determined by the voltage of the generators which is controlled by varying and reversing the fields. Full torque is available from the motors at any speed from zero to a maximum, in either direction, and the control is carried out by a single lever operating in conjunction with a potentiometer type regulator.

The simplicity and efficiency of this method of control compares very favourably with the operation of a Direct Diesel drive with its complicated reversing gear.

(4). *Low Upkeep Charges.* The provision of a number of comparatively small simple engines driving generators which run continuously at constant speed and in one direction will tend to reduce largely the cost of maintenance and repair, and it is to be expected that the general upkeep will be considerably less than with the heavier and more complicated engines necessary for the Direct drive.

(5). *Large Factor of Safety.* The sub-division of the generating plant into two or more units ensures that the failure of one engine will leave still available at least 50 per cent. of the total power, which will correspond to a speed on the boat of approximately ·8 full speed, an alteration to the electrical connections in the case of a twin-screw vessel putting both motors on to the remaining generating unit or units.

The reliability of the propeller motors is at least equal to that of any form of prime mover, but if an exceptionally large factor of safety is desirable the motors can be designed as double-armature machines, so that even should one-half fail the remainder would be available for half power. For large powers this sub-division may be desirable from other considerations, the chief of which is the overall diameter of the motor frames which will be considerably reduced by this course, although the length will be somewhat increased.

(6). *Steadiness of Running.* The characteristics of a direct-current motor are such that the speed is practically independent of the load, thus, should the screw lift from the water in a heavy sea, no racing would take place and the stresses due to sudden acceleration and the consequent blow when the propeller re-enters the water would be avoided.

The above advantages, whilst of great importance in themselves, omit two main considerations, namely, the cost of the equipment and the efficiency of running.

With regard to the former, it has been found that the Diesel Electric drive can compare in cost with that of the Direct Diesel drive, and future developments will probably result in the cost of the former being considerably less. This result accrues through the largely reduced cost of the higher speed, simple, continuous running engine as compared with a heavy, slow speed, reversing engine, and from the fact that Lloyds' Rules insist that with a Direct Diesel drive an additional compressor has to be provided of sufficient capacity to reverse the engine and to keep it running in the event of a failure of the engine compressor.

This additional compressor is unnecessary in the case of a multiple unit generating station. Further, a considerable saving in cost can usually be made in the Electric drive by the elimination of shaft tunnels through placing the motors as far aft as the lines of the vessel will allow.

The efficiency of running, *i.e.*, fuel consumed, is naturally of great importance, and at full load the Diesel Electric drive suffers to the extent of 10 per cent. due to the conversion losses in the electrical machinery. In actual practice this loss is likely to be less than the above figure, due to the fact that the slow speed Diesel directly connected to the screw must have a considerable margin of power to deal with unusually heavy conditions, and will consequently be running at something considerably less than full load, whilst with the number of machines used for the Electric drive they can work more nearly to the full power.

In speaking of full load as above, it has been taken that this corresponds to full speed on the vessel. At any speed less than ·8 of this the Electric drive can, however, more than hold its own, as this speed corresponds to only half load on the propeller motors, with the result that one or more generating units can be shut down and the remainder will work at full load or approximating thereto, whilst the direct-coupled Diesel naturally will run at half load with an increased fuel consumption per horse-power developed. This condition is of particular importance in the case of vessels of the refrigerator class, which operate at full speed when carrying a perishable cargo, but which return at about ·8 speed when loaded with general cargo. The average oil consumption under these conditions will compare very favourably for the two drives.

When considering the Turbine Electric drive as compared with the Turbine Geared drive, the advantages enumerated above will hold good and, in addition, full power is available for both " forward " and " reverse " running, which is not the case with the Turbine Geared drive. Also, a noiseless drive results, which is of importance when the equipment of a passenger vessel is in question.

The relationship of capital cost and efficiency of running differs however, since in this comparison the first cost of the Turbine Electric drive is somewhat more than that of the Geared Turbine.

The steam consumption at full load of the single gear reduction Turbine and of the Turbine Electric drive are strictly comparable, whilst the latter is more efficient than the double reduction Turbine, even taking the gear losses as low as 2·5 per cent. for the single reduction Turbine and 5·5 per cent. for the double reduction Turbine. It is very doubtful whether such high efficiencies on the gears can be maintained for any length of time.

When considering turbine drives three-phase machinery comes into question.

One of the reasons which account for the good efficiency of the Turbine Electric drive lies in the elimination of the " astern " turbine which avoids the continual idle losses of this portion of the plant, and allows at the same time of the use of superheated steam in the main turbines. It is not desirable to make use of too high temperature steam on the Geared Turbine drive owing to risk of trouble with the " astern " turbine during manœuvring due to the great changes of temperature between that of the condenser and of the live steam, representing the two conditions under which this turbine operates.

Choice of Electrical Plant and Propeller Motors.—As previously mentioned, the use of Diesel sets makes the employment of direct-current machinery desirable, to avoid any question of parallel running of the generating sets, and no difficulties of manufacture occur in the provision of direct-current motors up to any required size. Where, on the other hand, very large powers are required, a Steam Turbine drive is rendered obligatory from considerations of engine room space, and in this case three-phase generators are adopted with some form of three-phase motor directly coupled to the propeller.

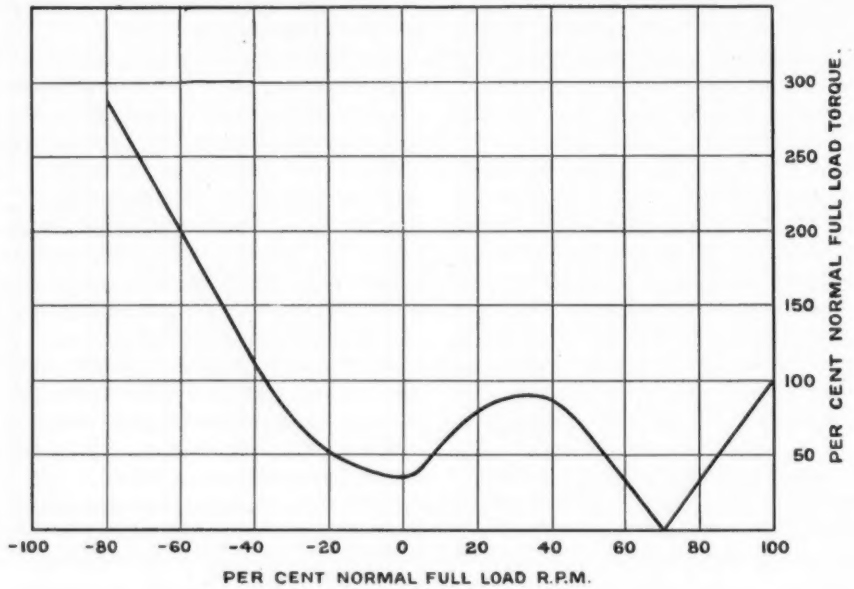


FIG. 1. FULL-LOAD TORQUE CURVE.

The design of the direct-current plant follows very closely that of heavy duty machines such as are employed for land work, in steel works, or for winding equipments, which are now so well-known that it is not necessary to go into detail.

The propeller motors, as a general rule, would be compensated machines suitably insulated to withstand sea-going conditions, and could be made up in the form of single or double-armature machines, depending on the space available, the power, and the desirability of having sub-division of the plant for greater security in operation.

The speed control, as mentioned above, is on the Ward-Leonard principle, and the pressure to earth would be limited to 700 or 800 volts.

The practice in regard to three-phase motors is not as yet standardized and various forms of machine have been adopted and proposed. The design of the three-phase motor is determined by two sets of conditions :—

(1). The fact that variable speed from zero to a maximum is required in both the " forward " and " reverse " direction.

(2). The loading condition which has to be met when reversing the vessel from " forward " to " astern " direction.

In Fig. 1, is shown a typical torque diagram of a propeller from " full ahead " to " full astern " speed. An analysis of this curve, starting from " full speed ahead " shows that, as soon as the driving torque on the motor is reduced to zero, the propeller speed falls to approximately 70 per cent. of full speed, and the way on the ship continues to drive the propeller at this speed in the original direction. Assuming now that it is required to reverse the propeller, a reverse torque is applied by the motor and the propeller starts to slow down. In order to bring the propeller to rest an increasing reverse torque must be applied until approximately ·8 of full-load torque is applied, at which point the propeller speed is

reduced to approximately 30 per cent. of "full forward" speed. After this point is reached the torque necessary to stop the propeller falls away rapidly and reaches a minimum of about ·25 full torque at zero speed. To accelerate the propeller in the reverse direction a constantly increasing torque is then necessary until "full speed astern" is reached. The curve in Fig. 1, is drawn on the assumption that the speed of the ship remains at constant value in the "ahead" direction, which in practice is not the case, but, as the time taken to carry out the reversal of the propeller should not be more than about twenty seconds, the curve approximates closely to actual conditions.

The requirement of considerable reverse torque whilst the motor is rotating in the "forward" direction does not render the plain induction motor a particularly suitable form of drive, although such machines have been utilized in conjunction with external resistances of either a constant or variable value.

The alternative forms of drive in use or suggested are as follows :—

(1). Synchronous Motor.
(2). Induction Motor with double-wound rotor.
(3). Cascade Motor.
(4). Asynchronous-Synchronous Motor.

Arising directly from the consideration of variable speed is the necessity of designing the propeller motor and its generator as one unit, inasmuch as the complete set operates at varying frequency and voltage. Particular attention has, therefore, to be paid to the reaction of the motor on the generator and the two must be designed together.

A brief description of the various forms of motor and their special features is as follows :—

(1). *Synchronous Motor.*

To make this type of machine suitable for giving the necessary reverse torque, a heavy damping winding is wound on the rotor, which acts in effect as a winding on an induction motor, providing the necessary torque for reversal of the screw.

The sequence of operations is then :—

(1). The turbine speed is reduced to idling speed, *i.e.*, approximately 25 per cent. of full speed.
(2). Both generator and motor fields are opened and the motor stator connections reversed.
(3). The field circuit of the generator is closed and over-excited to at least 50 per cent., which gives reverse-current braking on the motor and, later, sufficient torque for accelerating in the reverse direction to a speed corresponding to the low synchronous speed.
(4). The field of the motor is then closed and it pulls into synchronism, after which the turbine speed is raised to normal, giving full reverse speed on the propeller.

Although these operations are somewhat lengthy to set out, it will be realized that in practice, with proper interlocking, the sequence is very simple.

(2). *Induction Motor with Double-wound Rotor.*

This type of motor has been employed for a number of the battleship drives in the States. The rotor winding consists of a high resistance and a low resistance winding, the former contained in slots close to the periphery of the rotor, whilst the latter lies in a second row of slots immediately below the first, with a small air gap connecting the two sets of slots.

Under normal operation, *i.e.*, when only a low frequency is impressed on the rotor, the low resistance winding is in operation, but during reversal when the frequency on the rotor is high, the high resistance winding takes over the load and provides the necessary torque for reversal.

The method of reversal follows closely on that outlined above, but in addition, in one instance, the number of poles in the stator was increased from 24 to 36 during reversal, thus giving a still larger reversing torque. In other cases where the double-wound induction motor has been utilized, the high and low resistance windings have been placed in the same slots, a

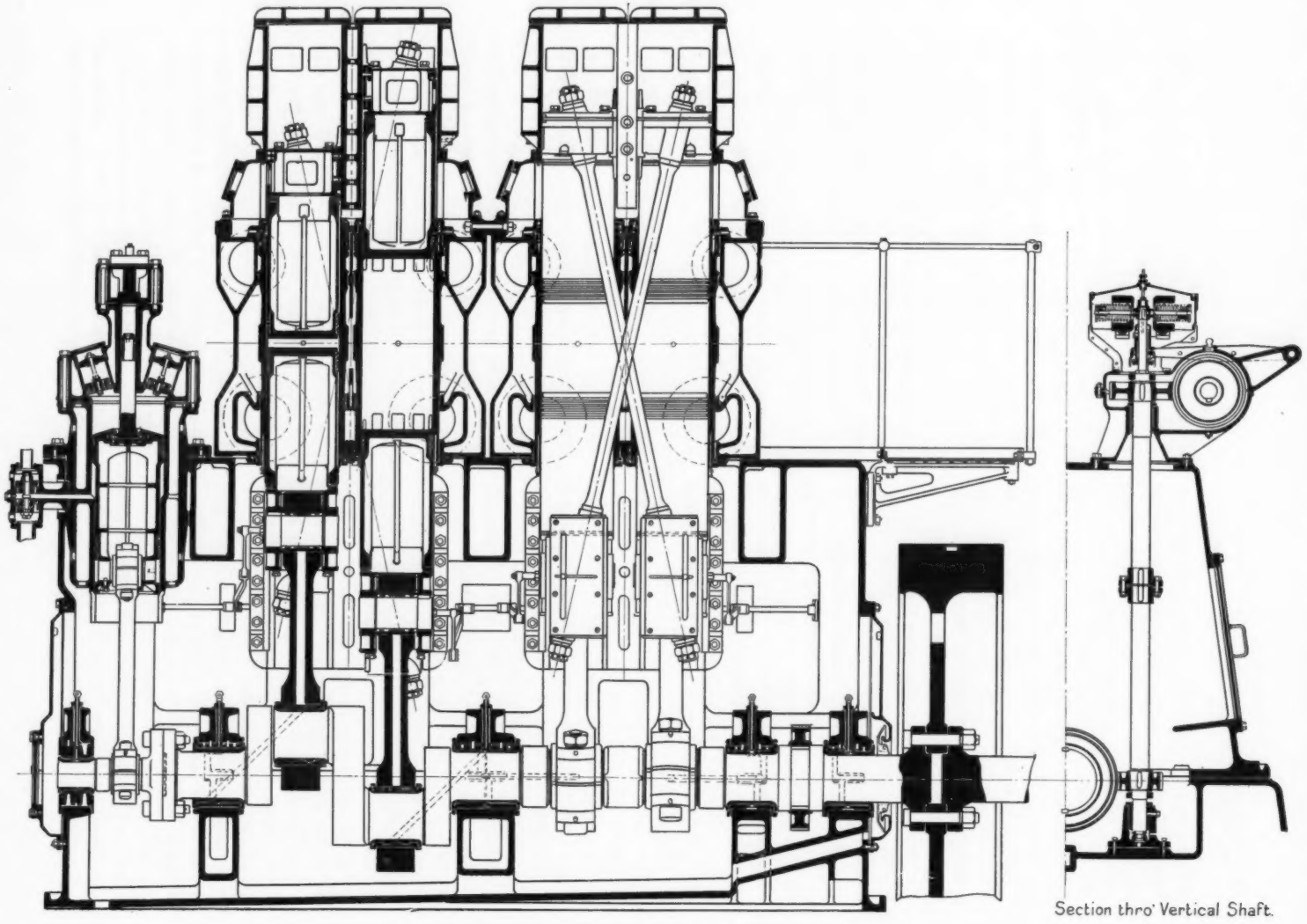


FIG. 2. SECTIONAL ELEVATION OF 750 B.H.P. FULLAGAR OIL ENGINE.

switch opening the low resistance windings at such times as the high resistance windings are required for giving the reversal torque.

(3). *Cascade Machines.*

The employment of this type of machine has advantages where two or three definite speeds are necessary, such as in the case of battleships where full speed and a cruising speed are required. A reduced speed for cruising is obtained with the turbine running at full speed, which allows of increased economy. Reversal in the case of such a machine would be carried out with the increased number of poles, which renders increased torque available, and external resistances would be used during this period.

(4). *Asynchronous-Synchronous Motor.*

This type of machine combines the advantages of the synchronous motor and of the induction motor and gives its starting and reversal torque as an induction motor, whilst running under normal conditions as a synchronous machine. This allows the control gear to be reduced to a very simple form, as the motor automatically changes from synchronous to asynchronous operation by opening the D.C. exciting circuit.

Power Factor and Efficiency.—With a view to reducing the size and weight of the generating set, it is desirable to have for the propeller motors, machines of the synchronous or asynchronous-synchronous type, as these operate at unity power factor under all conditions of load, whilst at the same time having a higher overall efficiency than that of the corresponding induction motors.

The size of the cables between the generators and motors are also reduced, and these advantages would point to the adoption of such types as the machines of the future when turbine electric drives are under consideration.

Referring back to the comparisons of weight and space between the Diesel Electric drive and the Direct Diesel drive, the engine put forward for driving the generators is of the Fullagar type. This type of engine, though of comparatively recent origin, has proved remarkably successful, both for the slow speed engine for direct-coupling to the screw, and also as a high speed engine for driving generating plant. It is of the two-stroke cycle, opposed piston type, with the cylinders arranged in pairs and with cross connecting rods between the upper and lower pistons of each pair of cylinders.

Compression and explosion take place between the two pistons, and power is transmitted directly from the lower piston to the crank immediately beneath it, whilst the upper piston transmits power to the adjacent crank through the cross connecting rods. By this means a very well-balanced engine is obtained.

A cross section of a four-cylinder four-crank engine is shown in Fig. 2, in which the main details can be seen. It will be noticed that each line of pistons has only one crank, the cross connecting rods taking the place of the cumbersome external rods, used on other forms of opposed piston engines, which necessitate the use of additional cranks on the main shaft.

The movement of the pistons uncovers two sets of ports when in the extreme position, the upper ports serve for the exhaust, whilst the lower ports form the inlet for the scavenging air. The cylinder is thus swept entirely free from the burnt products by the incoming scavenging air.

The upper crossheads are arranged to work in cylinders and thus to supply the scavenging air required. The power necessary for this purpose is transmitted through the cross connecting rods, thus relieving the crank shaft of the engine.

The simplicity of the cylinder casting is obvious, consisting as it does of a practically plain cylinder, and the fact that the explosion takes place between the two opposed pistons renders unnecessary the provision of the heavy cylinder head required for the normal type of Diesel engine.

The scavenging air inlet and exhaust openings are formed in the walls of the cylinder and

FIG. 2. SECTIONAL ELEVATION OF 750 B.H.P. FULLAGAR OIL ENGINE.

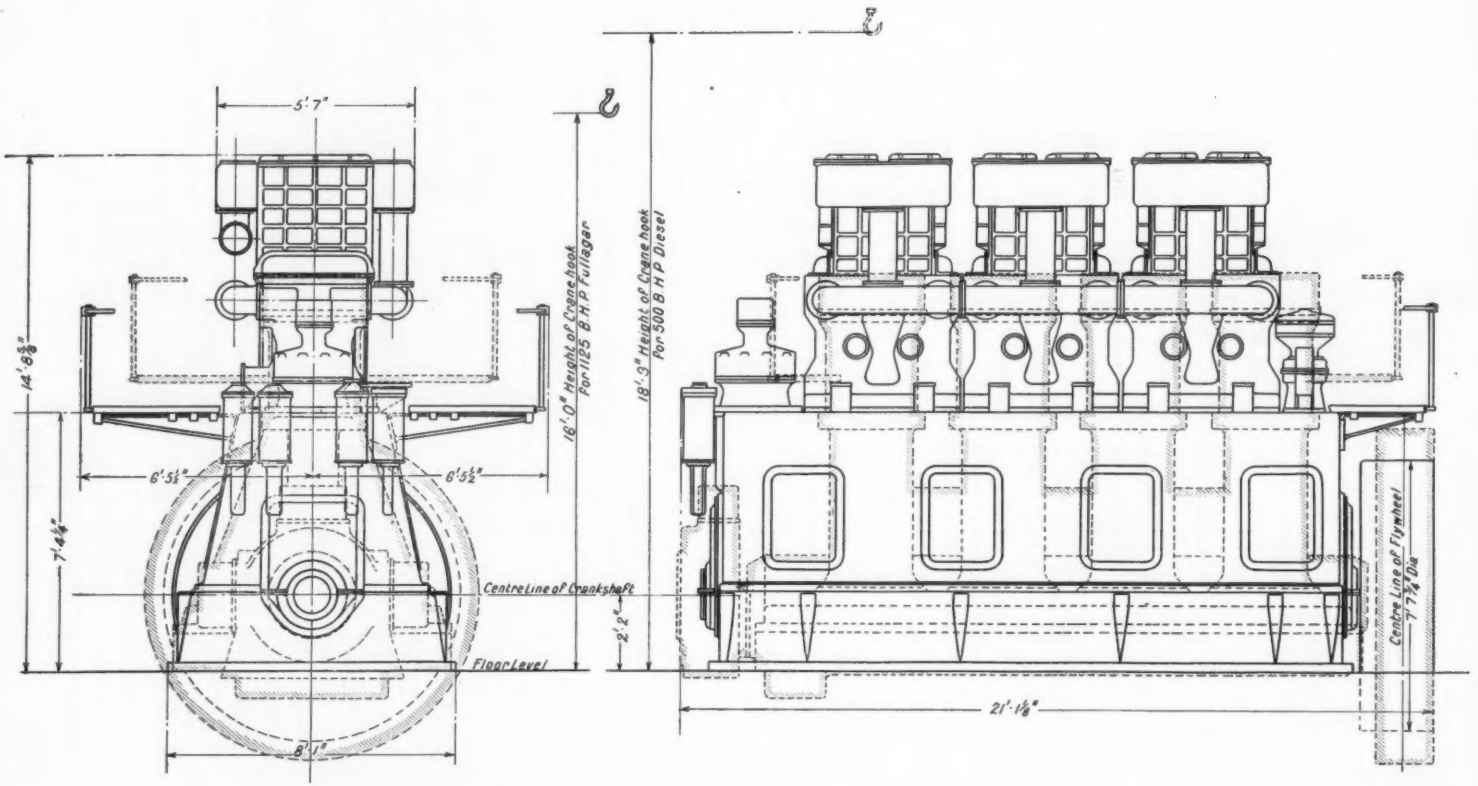


Fig. 3. Comparison between 1125 B.H.P. Fullagar Engine and 500 B.H.P. Standard Diesel Engine.

are opened and closed by the movement of the pistons. External moving valves with their operating mechanism are thereby avoided.

The turning effort of a four-crank Fullagar is equal to that of an eight-crank ordinary Diesel working on a four-stroke cycle.

A comparison in dimensions of a 500 h.p. standard four-stroke Diesel and a 1,125 h.p. Fullagar engine is made in Fig. 3. It will be seen that the length and breadth of the engines are practically identical, but that the height of the latter is somewhat greater. In most cases this additional height is of little moment, and from the crane point of view less height is required to dismantle the Fullagar engine than is necessary in the case of the standard Diesel engine.

An external view of a 750 h.p. Fullagar driving a generating set at 250 r.p.m. is given in Fig. 4.

In the case of the Direct Diesel driven vessel it is frequently desirable to adopt a twin-screw design in order to keep the speed of the engines as high as possible on account of questions of weight and space. This consideration does not hold for the electrical drive, in that there is no difficulty in choosing the slower speed desirable for a single screw. It is possible that a general adoption of the electrical drive will result in an increased use of the single-screw boat, as thereby considerable reduction in appendage resistance and an increase in propulsive efficiency are obtained, whilst the slower speed propeller is itself slightly more efficient.

The lay-out, Fig. 5, shows the relative space taken up by the propeller motors in the case of a single-screw and twin-screw vessel of the cargo class, and the advantage of the adoption of a single motor from the point of view of space occupied is obvious.

The generating plant for such a drive would be unaltered whether the boat was of the single or twin-screw type. Two generating sets

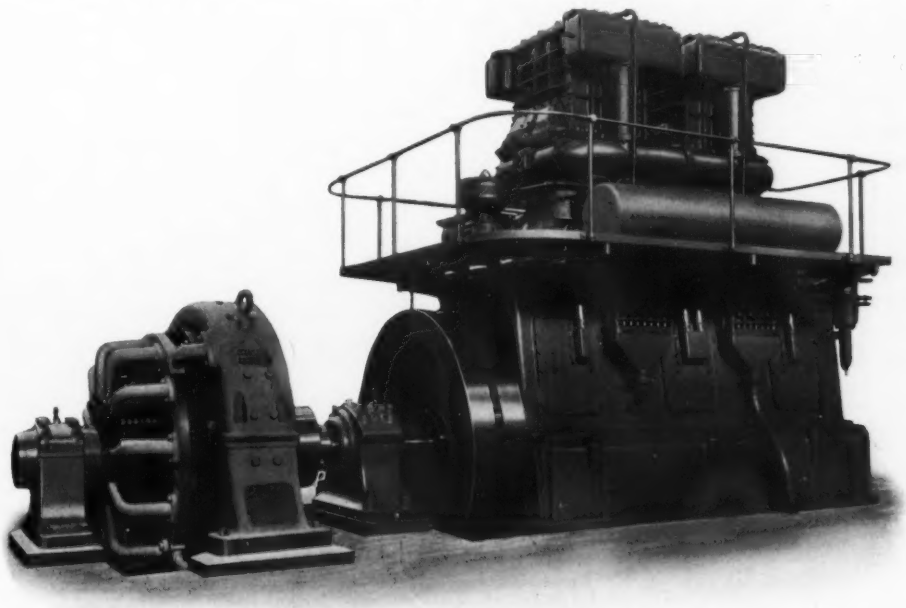


FIG. 4. A 730 B.H.P. FULLAGAR ENGINE DRIVING A D.C. GENERATOR AT 250 R.P.M.

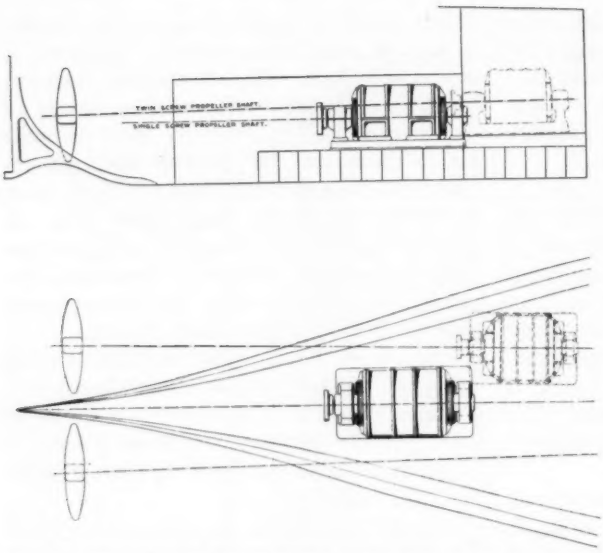


FIG. 5. COMPARISON OF SPACE TAKEN UP BY MOTORS IN A VESSEL OF THE CARGO CLASS FOR SINGLE AND TWIN SCREWS RESPECTIVELY.

would be employed in each instance, one feeding each of the twin-screw motors, or alternatively working in series supplying power to the single-screw motor.

The motors shown in the illustration are, in both cases, of the double-armature type in order to reduce the diameter of the frames to a minimum, so permitting of their being placed further aft.

The relative reduction in diameter on a motor of 4,200 h.p. at 120 r.p.m. is shown by Fig. 6.

When urging the adoption of a new form of drive, the question of reliability is inevitably raised, and there will no doubt be a great deal of anxiety on this score for a certain period.

The numberless applications for which the electric drive has been adopted have proved that its reliability is equal to, if not better than, any form of prime mover, and if this fact is not sufficient it is possible, without difficulty, to sub-divide the electrical plant in such a way that complete failure is practically impossible.

Thus, for example, the propeller motors may be built up in the form of a double unit, each half independent of the other, so that should one half fail it is still possible to develop half power in the other. The provision of a number of generating units also renders the possibility of a complete shut-down most unlikely.

The general upkeep charges should also be low on account of the simplicity of the units.

Power Variations.—A series of extensive experiments have been made to determine the power variations that may occur on the propelling equipment under various conditions. It has been found that with the ship steaming full speed ahead and the rudder thrown hard over, the power on the inboard screw may rise to 50 per cent. above normal load, whilst the load on the outboard screw would fall by about 25 per cent. As the turn is completed, the power of the inboard screw will gradually fall away, and that of the outboard screw rise, until they become equal again.

When meeting very heavy weather big variations in screw power may occur, either through the propellers leaving the water, or

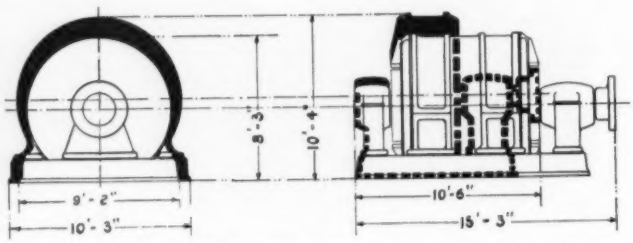


FIG. 6. RELATIVE DIMENSIONS OF SINGLE AND DOUBLE-ARMATURE DESIGNS FOR A MOTOR OF 4,200 H.P. AT 120 R.P.M.

from the impact effect of a wave. Under these conditions very heavy overloads can occur if the boat is being propelled at full speed, but it is more usual to slow down. Under these circumstances, although the power variations may be as much as 100 per cent., these occur on a reduced normal power and do not represent so great a percentage of the normal rating of the machine. In order, however, to limit the stresses induced by such heavy loading conditions, it is possible to so design the generating sets that they will slow down in the event of an excessive demand being made for power, in which case the speed of the propeller motors will fall until the load demand of the screws comes within their capacity.

Number of Electrically Propelled Ships.—The total number of ships built and under construction up-to-date is about 60, and of these a considerable number have been under trial with excellent results, and the fact that all except seven of these boats have been put in hand since 1918, shows the confidence which the first examples have engendered.

Drives for Battleships.—Under the first ship-building programme the United States laid down seven battleships of 33,000 tons, each with a total power of 28,000 s.h.p.

The first ships so built were very fully tested out under all conditions and gave extremely satisfactory results. Published figures of a test on the *New Mexico* in comparison with two other steam driven ships of a similar class give the following savings in oil fuel consumption for the electrically propelled boat :—

At 10 knots a saving of 20 per cent.

At 13 knots a saving of 42·7 per cent.

At 16 knots a saving of 48 per cent.

At 19 knots a saving of 40·1 per cent.

The *Tennessee*, a later ship than the *New Mexico*, showed even better results.

The above ships have four screws, each driven by an induction motor of 7,250 h.p., two turbo-alternators supplying the necessary power.

On the results of the first electrically propelled battleships it was decided that future battleships should be equipped with this form of drive, and, until the limitation introduced by the Washington Conference, the programme included six additional 43,000 ton battleships with a total power of 60,000 s.h.p. and six battle cruisers of 43,500 tons, each equipped with a total power of 180,000 s.h.p. Work has been stopped on these boats, but two aeroplane carriers are under construction with a similar power to that of the battle cruisers, *i.e.* 180,000 s.h.p., and these equipments are finished at the present time.

Even discounting special features which make the Electric drive particularly suitable for battleships, it is impossible to give a better proof of the place which this form of drive is likely to fill in the future.

Three of the main advantages of the Electric drive as applied to war vessels are :—

(1). The fact that under normal conditions a low efficient cruising speed is necessary as this represents the normal operating speed of the vessel.

(2). The possibility of centralizing the control in such a way that maximum protection can be given against casualty.

(3). The superior manœuvring qualities of the Electric drive.

When considering the installation of the Electric drive for ship propulsion it must be borne in mind that to obtain the maximum efficiency it is extremely desirable that, at any rate, a large proportion of the auxiliaries should also be electrically driven, and there is no doubt that, just as in the case of land installations, very great economies result from the conversion of the auxiliaries to the Electric drive.

Reversing Mill Drive at Messrs. Cammell Laird and Co.'s Penistone Works.

The present article describes the general lay-out of the plant installed at Messrs. Cammell Laird's Penistone Works for the purpose of driving their 34-in. Reversing, Roughing and Finishing Section Mill, which embodies a number of unusual features of considerable interest.

When the lay-out of the plant came under discussion it was found that if the Ilgner set and auxiliary apparatus required in connection with the mill motor were placed adjacent thereto, the amount of mill floor space available would be very seriously restricted, and the question arose as to how this could best be avoided.

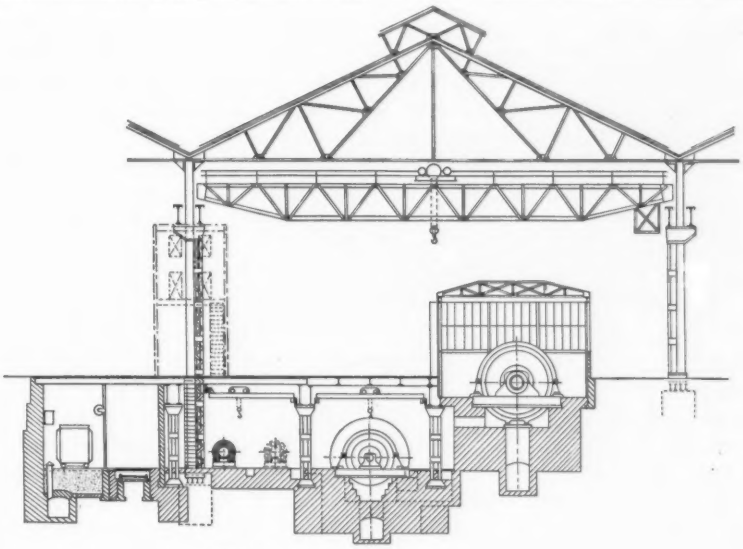
One of the suggestions was to place the Ilgner set at a considerable distance from the mill motor, but this would have entailed two buildings and additional superintendence; it was finally decided to place the whole of the plant, with the exception of the mill motor itself, in an underground chamber, the roof of which was made of sufficient strength to serve as the mill floor. By making this roof in sections, of which some are removable, easy access to the underground machinery can be obtained, and it can be handled by the main mill crane which runs immediately above. The dimensions of this underground chamber are 103 ft. × 76 ft. × 17 ft. high, and Fig. 1 shows a plan view and two elevations of the final lay-out. In the plan view, the full lines represent plant at present installed and the dotted lines show the space available for future extensions, which cover the supply of a second Ilgner set coupled to the first for the purpose of providing power for a reversing motor for the Cogging Mill Stand.

The transformers, which take power from the Yorkshire Electric Power Co. at 10,000 volts, 50 cycles, 3-phase, are placed in an entirely enclosed chamber shown on the left of the plan. Not only is the transformer chamber, as a whole, separate from the rest of the building, but each of the transformers, which are of the single-phase type (three together forming a 3-phase bank), is housed in a separate brick compartment with an iron shutter in front.

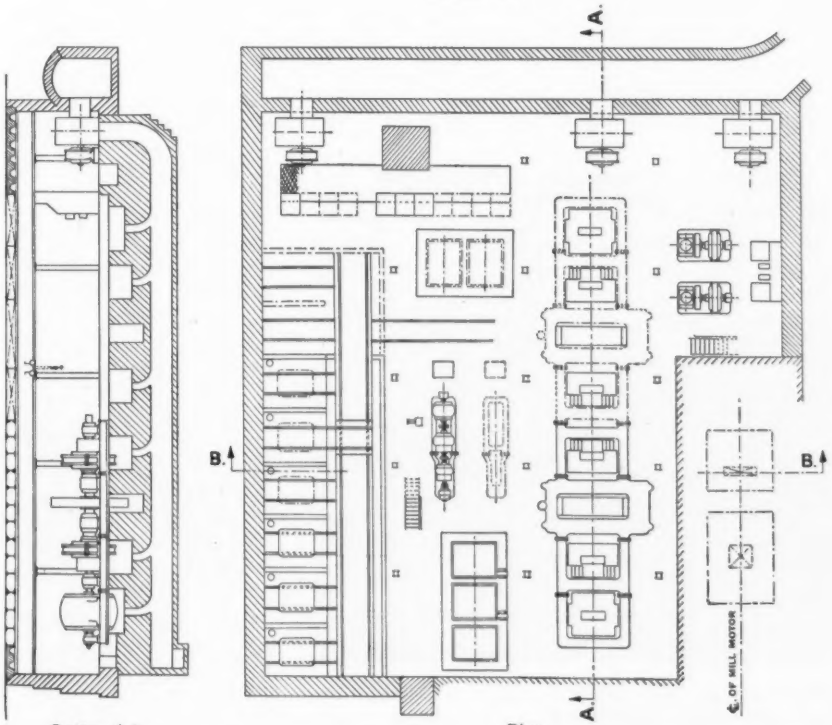
In order to facilitate prompt repair of any transformer, each is mounted on a truck with flanged wheels, so that it can be drawn forward, transferred to a bogey which runs along the front of the compartments, and run out of the transformer house into a position where it comes immediately below the main crane. The transformer rails are mounted on narrow concrete piers which are surrounded by broken granite chips up to the level of the rails. This device obviates the risk of fire, as any oil which may escape percolates through to the bottom and drains off to a sump. In order to get rid of the heat generated in each of the transformer cells a special supply of filtered and cool air is led into each cell and escapes through louvres in the top of the sheet steel doors. Further reference to the cooling system adopted is made later.

Adjacent to the wall of the transformer house are placed the exciter set and the automatic slip regulator, whilst on the right of the building is the Ilgner set consisting of driving motor, two generators and steel built-up flywheel. The side of the underground chamber on the right of the Ilgner set is formed by the foundation of the mill motor, and by having suitable ducts leading through into the pits below the mill motor frames, a short and convenient run of copper connections is obtained between the generators and the mill motor.

The present flywheel set, as mentioned above, is of sufficient capacity to supply the existing 19,000 H.P. mill motor. The future extension,



Section BB.



Section AA. *Plan.*

FIG. 1. GENERAL ARRANGEMENT OF UNDERGROUND SUBSTATION AND MILL MOTOR.

when a cogging mill motor is put down, will comprise two further generators, a flywheel and an additional driving motor, and in conjunction therewith an additional exciter set, automatic slip regulator, switchgear and bank of transformers will be required. The total continuous capacity of the plant finally to be arranged in the substation will be approximately 20,000 KW., and the heat emitted due to the unavoidable losses, will naturally be very considerable.

The use of an underground substation means that it is practically heat-insulated, and consequently special methods are necessary for keeping the temperature within reasonable limits. To ensure this result two motor-driven fans are installed, each capable of blowing 40,000 cubic feet of air per minute, whilst a third fan of the same capacity provides the necessary cooling air for the mill motor itself. The main air duct from which the three fans draw their supply is arranged at the end of the station, and the ducts leading from the fan outlets are clearly seen both in the plan and elevations. Of the latter, the section on "AA" shows the duct opening up under the machines of the flywheel set, and the section on "BB" that leading to the mill motor. A further duct passes under the transformer chambers and has outlets into each of the separate compartments.

The incoming air is taken from one side of the Works some little distance away from the mill in order that the air shall be as clean as possible and is drawn by means of the fan suction through a filter of the dry cloth type to ensure clean air for the sub-station and mill motor. Two of the fans are shown in Fig. 2; the air is drawn through the wall into the eye of the fan, which discharges vertically downward into the ducts underneath the floor, and finally leaves the building by suitable chimneys taken up into the mill.

Fig. 3 shows a general view of one end of the underground substation, showing the flywheel set on the left and the exciter set and slip regulator on the right. The lighting is by means of semi-indirect fittings containing ½-watt lamps, and the white tiled walls and light-coloured roofing ensure a very even illumination.

As the ceiling is formed of pressed steel, precautions are necessary to prevent sweating, and this result has been obtained by covering the underside of the steel girderwork with powdered cork.

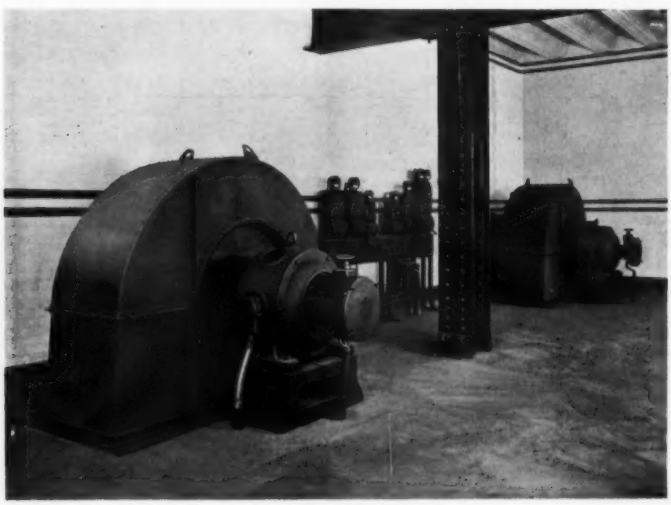


Fig. 2. Forced Draught Fans Supplying Cooling Air to Mill Motor and Substation Plant.

To facilitate the removal of bearing pedestal covers and the lifting of comparatively light parts without it being necessary to remove the roof and make use of the main crane, a light hand-operated crane is arranged to run on angle-iron rails supported from the main longitudinal girders. One of these rails is clearly seen in Fig. 3.

The incoming 10,000-volt supply is led directly into the high-tension stonework switch pillar shown in

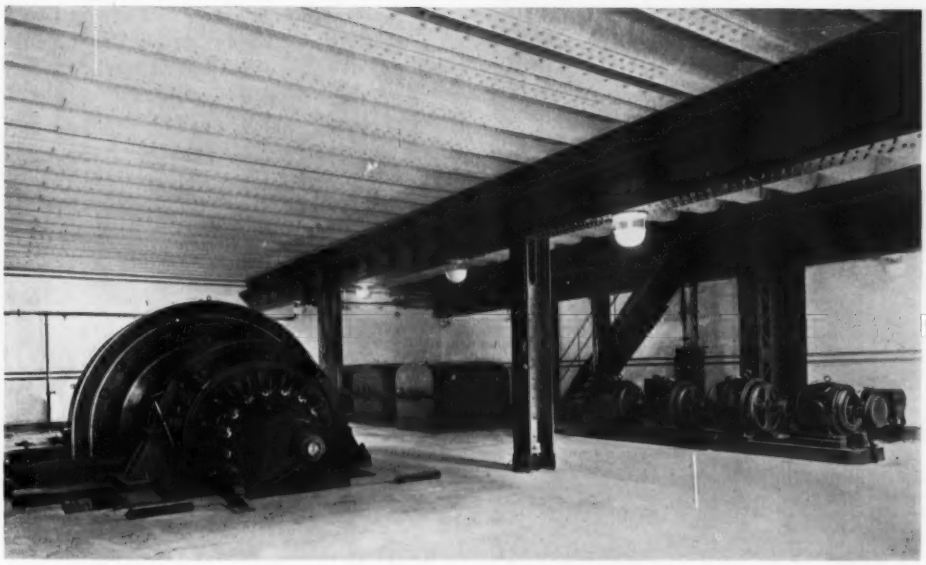


FIG 3. VIEW IN UNDERGROUND SUBSTATION, SHOWING GENERATOR END OF CONVERTER SET, EXCITER SET AND SLIP REGULATORS.

Fig. 4, which although at present a single unit, is arranged so that at a later date further pillars can be placed adjacent with common bus-bars. This incoming pillar carries the necessary voltmeter, ammeter and integrating wattmeter, and controls the supply to the high-tension side of the transformers through isolating switches and three single-pole oil switches coupled together to form a three-pole switch. Each pole of the oil switch is placed in an independent stonework cell. Feeder protection gear on the "Merz-Price" system is mounted in a separate cell at the base of the pillar.

The outgoing cables pass to the high-tension side of the three main single-phase transformers, the design and arrangement of which are shown in Fig. 5. The capacity of each single-phase transformer is 1,220 KVA. with a voltage ratio of 10,000/3,000 volts. In order to keep the transformers entirely separate from one another the bare copper connections are not taken directly through the separation walls, but are connected to copper stalks which are cemented into through insulators, these latter being mounted in a cast-iron plate which is built into the wall. The arrangement of the rails and broken stone filling is clearly seen from the illustration. The pipe and cowl on the right serve as the inlet for the air of the cooling system.

From the low-tension side of the transformers cables are taken to 3,000-volt feeder switch pillars of a type generally similar to those illustrated in Fig. 4. These pillars are at present arranged as a set of three, one acting as the incoming panel and the other two forming outgoing feeder pillars to the motor of the flywheel set and the motor of the exciter set respectively. Arrangements have been made in this case also to allow of the board being extended at a later date.

The outgoing feeder cables to the flywheel set are carried in ducts underneath the floor direct to the pit beneath the motor of the set, a general view of which is seen in Fig. 6. The driving motor appears on the right-hand

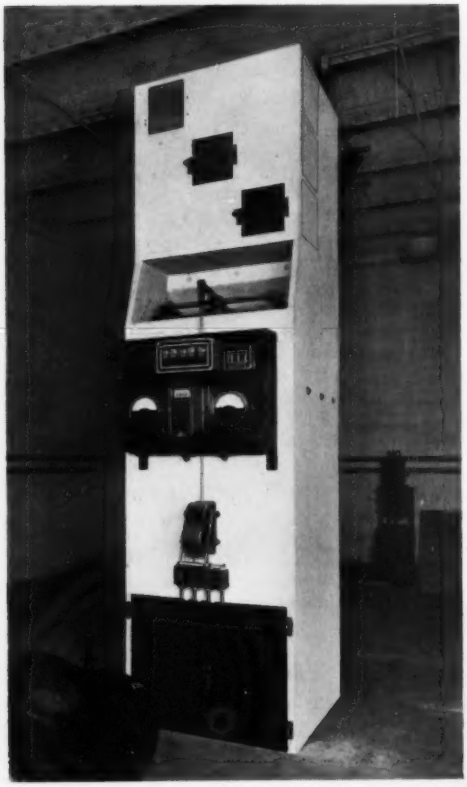


FIG. 4. H.T. STONEWORK SWITCH PILLAR FOR 10,000-VOLT SUPPLY.

side of the picture, and adjacent to this is one of the variable-voltage generators, the flywheel being arranged between this generator and the second one. This position of the flywheel has the advantage that on heavy loads when the flywheel is giving up a portion of its stored energy, this energy is transmitted in both directions through the shaft, thereby reducing the stresses in this shaft as well as in the couplings and shafts of the variable-voltage generators.

By designing the bearings carrying the flywheel of sufficient size to take half the weight of the generator, the number of bearings of the whole set is reduced to five; the use of solid couplings throughout has contributed to shorten very considerably the overall length of the set and does away with the complication of flexible couplings.

The driving motor has a continuous output of 3,850 H.P. at 428 R.P.M. (synchronous), whilst the continuous rating of the two variable-voltage generators which operate in series is approximately 4,500 KW.

The flywheel is of the built-up type, and consists of a forged steel spider, on to the periphery of which are bolted two cast-steel rings. The total weight of the wheel is 46 tons, and the outside diameter 14 ft. 3 in.

The advantages of the built-up type over the complete cast wheel are as follows —

(1) The elimination of casting stresses,

(2) a greater weight of metal is in the rim where it is of most use, and

FIG. 5. 1,220 KVA. SINGLE-PHASE TRANSFORMER AND CHAMBER.

(3) the weight to be handled during erection is reduced by approximately one-half.

The bearings carrying the flywheel are both ring and pressure lubricated, and in order to overcome the starting difficulties the pressure used is of high order, roughly 150 lbs. per square inch; this is sufficient practically to lift the flywheel on a film of oil. Motor-driven pumps provide the supply during the starting period, with the result that the current taken by the driving motor during starting is well below normal full-load, and barring gear is rendered unnecessary.

After the set reaches half speed, oil pumps, which are belted from the main shaft, provide the necessary supply, and the motor-driven pumps are shut down to act as a standby. The heated oil after leaving the bearings flows back through filters into a tank fitted with cooling coils. To meet emergencies, a band brake is fitted to the bottom half of the flywheel, and this is made of sufficient strength so that the flywheel can be lifted off the bearing seats in the event of inspection of the bearings being necessary. A sheet-steel guard over the periphery of the wheel reduces the windage loss to a minimum.

The design of the variable-voltage generators, which have to meet the heavy peak loads demanded by the mill motor, is necessarily special. The armature spiders and frames are of cast steel and the main poles carry compensating windings. The commutators, which deal with currents up to a maximum of 10,000 amperes are of the double type, each half being supported on " V " rings, a construction which gives four times the strength of a single bar double the length. The connections between the two halves of the commutator act as fans and so ensure satisfactory cooling.

The illustration of the flywheel set gives a good idea of the robust construction of these machines. The bedplate is of very heavy design, the various portions being bolted together and sunk into the concrete to a level practically flush with the surface.

The connections between the variable-voltage generators and the mill motor are composed of five bare copper strips each 4 in. $\times \frac{1}{4}$ in., suitably spaced and carried by heavy busbar type insulators. They are taken from the pits beneath the variable-voltage generators through ducts to the wall, up which they pass vertically to the level of the ducts leading into the mill motor pits. The connections between the various mill motor armatures are taken horizontally along the wall, and are seen just above the frame of the variable-voltage generator in Fig. 6. Suitable links are arranged in these copper connections so that, should one of the mill motor armatures fail, it can be cut out of circuit and the mill can be driven by the remaining two. Fig. 7 is a general view of the mill motor, the elevation arrangement of which is shown in Fig. 1.

The motor is designed to give a maximum peak output of 19,000 H.P. at a speed of 60 R.P.M., and has its speed variable between 0 and 60 R.P.M. at full torque, and between 60 and 140 R.P.M. at constant horse-power. Some interesting particulars of this machine are as follows :—

Weight (total)	320 tons.
Weight of each armature	45 tons.
Diameter of shaft in bearings	25 inches.
Pressure across the three armatures	1,400 volts.
Maximum current ..	10,000 amperes.

The motor is of the three-armature type, which, for these large powers, has a number of advantages which may be summarized as follows :—

(1) The diameter of the armatures is less than in the case of a double-armature machine with the same power, with resulting reduced inertia and improved operation.

(2) The distance between bearing centres is less, and the weight between bearings is reduced, with a correspondingly stiffer machine.

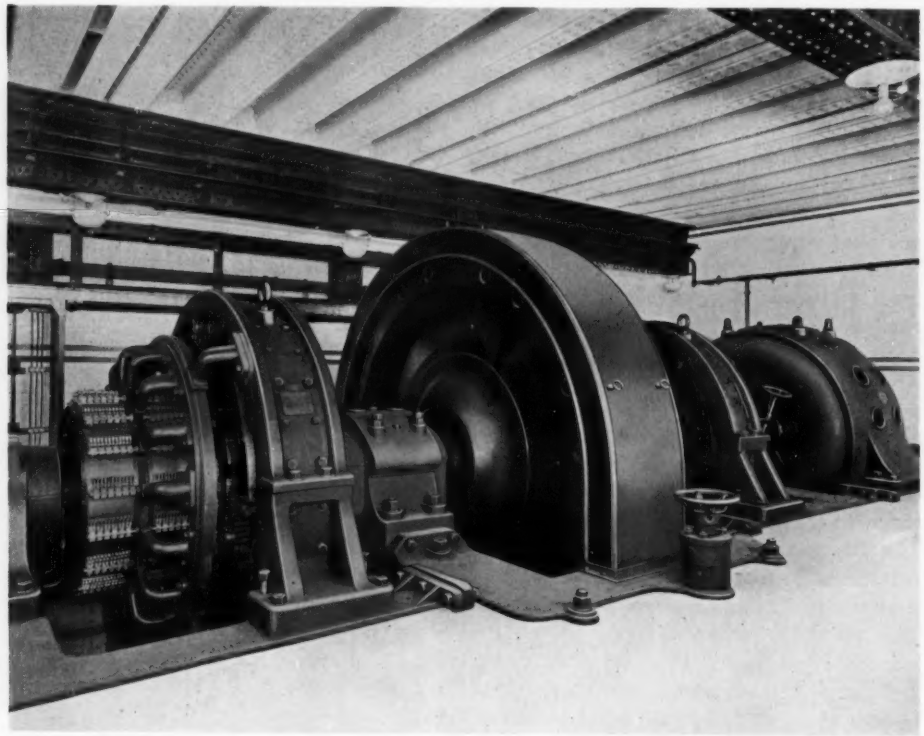


FIG. 6. VARIABLE-VOLTAGE GENERATOR SET WITH FLYWHEEL AND DRIVING MOTOR.

(3) The total weight of the motor is divided into an increased number of less weighty parts, which facilitates handling.

(4) A failure on one armature will leave two-thirds of the total power available for rolling.

The load cycle of a reversing mill represents almost as severe a duty as can be imagined, the load ranging from zero to a maximum twelve to fourteen times per minute with an equal number of reversals in direction of rotation. This necessitates special construction in many particulars, of which a few may be noted.

A steel construction is utilized throughout, *i.e.*, the armature spiders, commutator centres and frames are of cast steel. The core plates are secured to the spiders in a special manner to withstand the racking action produced by the frequent reversals. The drive between the various armatures is made through a special steel coupling piece and self-adjusting keys, so that no driving stress occurs in the connecting bolts. The armature windings are rigidly supported at the ends of the overhang to prevent movement on reversal.

The pedestals, bedplate, holding-down bolts, etc., are of specially heavy construction, and to ensure greater rigidity against movement of the bedplate it is sunk into the foundation to the level of the top of the bedplate in a similar way to that adopted for the flywheel set.

The motor on account of its frequent periods of rest is not self-cooling, and one of the motor-driven fans previously mentioned blows cool clean air through specially arranged ducts into

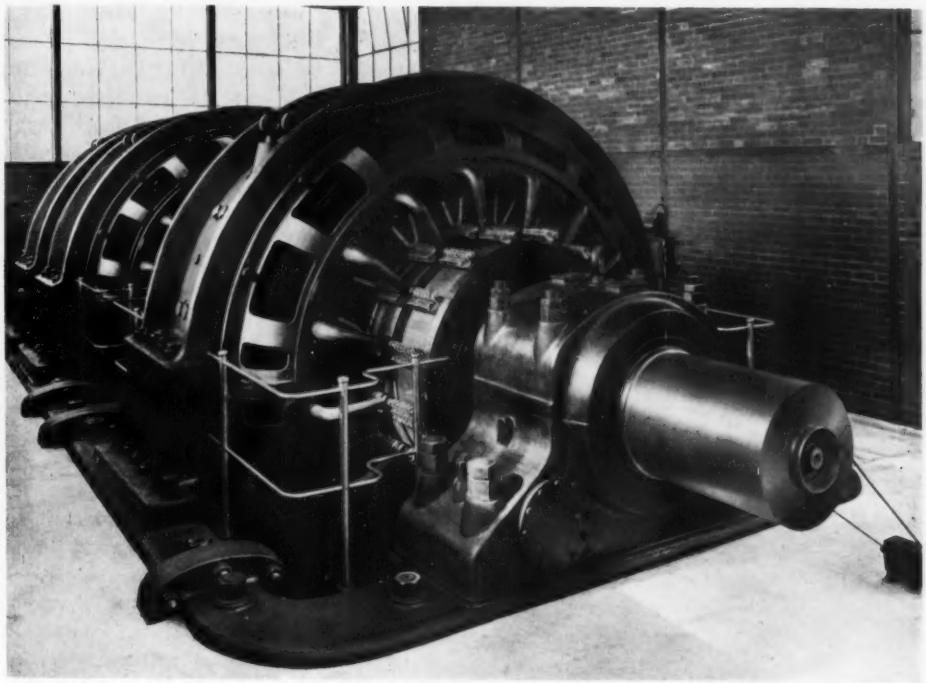


FIG. 7. GENERAL VIEW OF 19,000 H.P. MILL MOTOR.

the machine at the rate of 40,000 cubic feet per minute. This air is deflected by means of baffles through the field system and armature system of the machines, and air spaces are left in the centre of the armature and poles so that the armature bars and compensating windings are cooled in the centre of the armature and poles respectively, these positions corresponding to the hottest points.

The bearings are ring lubricated, this having been found sufficient for normal running conditions, but a small motor-driven oil pump acts as a standby in case of emergency.

The control of the set has been simplified to the greatest possible extent and the operation of the plant is carried out entirely by the operating lever and faceplate controller, shown in Fig. 8. The whole of the control is carried out on the fields of the exciter set, with the result that the main controller is of quite small dimensions.

The lever, which is of the railway signal type, in the central upright position gives zero voltage on the exciter of the variable-voltage generators. A "forward" or "backward" movement strengthens this exciter voltage in the one or other polarity, which, by its action on the fields of the main variable-voltage generator, gives a rotation on the mill motor in the one or other direction. The strengthening of the variable-voltage generator fields continues until a speed of 60 R.P.M. is reached, and during this period the field of the mill motor is at full strength, so that full torque is available. A further movement of the control lever then weakens the field of the mill motor through its action on the field of the mill motor exciter, giving a speeding up from 60 to 140 R.P.M. at constant horse-power.

The driver whilst operating the controller stands immediately in front of the instrument desk which carries an ammeter indicating the current taken by the mill motor, and two speed indicators, one giving the speed of the mill motor and the other that of the flywheel set. The height of the desk is such that a view of the mill is not impeded.

In earlier plants it was considered advisable to place a main circuit breaker in the mains between the variable-voltage generators and mill motor, which operated in the event of an overload occurring. This has now been found to be unnecessary, and a relay astride the mains operates a contactor which opens the field of the exciter controlling the variable-voltage generator; thus in the event of an overload, the voltage of the variable-voltage generator is reduced to zero and the mill motor is brought to rest. An interlock between the control lever and the contactor makes it necessary to pull the control lever back to the " off " position before the contactor can be re-closed, and the driver has this closing under his control through a push button on the instrument desk.

From the above description it will be seen that only small control wires are taken to the control platform, which is arranged above the roller train on the incoming side of the mill, and adequate protection is provided by running the wires in steel tubing.

The mill itself consists of three stands—cogging, roughing and finishing—the centres throughout being 34 in. As at present arranged, the cogging stand is driven from a steam engine, the roughing and finishing end being coupled to the motor. The cogged material is brought to the roughing and finishing mill in a size suitable for the required finished section, which may be rails, channels, girder sections up to 24 in. × 7½ in. or other heavy sections. As an average, the output from the mill will be in the neighbourhood of 45 tons per hour, but much greater tonnages than this will be reached on the larger sections. In practice it has been found that the operation of the roughing and finishing mill is so rapid that it can easily deal with the full output from the cogging mill, and the plant has proved entirely successful since setting to work.

In conclusion it may be stated that the experience embodied in this plant as regards design and construction, and particularly the constants adopted for the rate of acceleration, have proved themselves completely adequate to meet the most severe conditions.

FIG. 8. OPERATING LEVER AND FACEPLATE CONTROLLER.